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ABSTRACT

Naval auxiliary vessels carry considerably less cargo than commercial vessels and are significantly more costly to build. By comparing Naval Auxiliary vessels with commercial vessels which carry cargo of a similar nature it is possible with the method used in this analysis to quantify and explain the differences which exist between the Naval Auxiliary and commercial vessels. The design differences and a significant portion of the cost differences are the result of differences in ship mission, the military capabilities of the Naval Auxiliaries, and the differences in design criteria and practices used by Naval and commercial designers. The analysis is accomplished by comparing two Navy dry cargo replenishment vessels with three merchant break-bulk cargo vessels and by comparing a Navy fleet oiler and a Navy replenishment oiler with three commercial tankers. The largest factor which influences the design of the Naval Auxiliaries is the underway replenishment capability. The military capabilities also have a significant impact on the design of the Naval vessels, particularly with the oilers. Differences in design criteria and practices used by Naval and commercial designers are reflected mainly in the structural and main propulsion areas.

Thesis Supervisor: Clark Graham
Title: Adjunct Professor of Naval Architecture

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(6) A COMPARATIVE ANALYSIS OF NAVAL AUXILIARY
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by

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A COMPARATIVE ANALYSIS OF NAVAL

AUXILIARY AND MERCHANT SHIP DESIGN

by

James Patrick Dunn, Jr.

Submitted to the Department of Ocean Engineering on 12 May 1978 in partial fulfillment of the requirements for the degree of Ocean Engineer and the degree of Master of Science in Shipping and Shipbuilding Management.

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CHAPTER 1

INTRODUCTION

The acquisition costs of Naval replenishment vessels are staggering. In 1978 dollars, the acquisition cost for the lead ship in the AO-177 class is in the vicinity of $150,000,000. This figure includes the lead ship engineering costs, so that follow on ships in the class will be somewhat less expensive to build. Even so, the cost of these vessels is still remarkable and has forced the Naval auxiliary designer to seek means of reducing the acquisition cost. In an attempt to find a less expensive solution, the naval designer is led to look at commercial vessels which carry cargo of a similar nature. The acquisition cost for the lead ships in each of two recent Maritime Administration subsidized tanker classes are in the vicinity of $46,000,000 in 1978 dollars. These two tanker classes are about 75% larger than the AO-177 as measured by full load displacement. The difference in the acquisition cost between the Navy oiler and the commercial tankers raises questions as to why the acquisition costs of the Naval vessels are so high.

In general, there are four reasons why the acquisition cost of a Naval vessel may be greater. First, there is a difference in the mission of the vessels. The commercial vessels are designed to transport a specified amount of cargo from point A to point B at minimum cost. The Naval auxiliaries, while capable of transporting cargo from point A to point B, are designed primarily to transfer the cargo at sea to other

fleet units. Second, the Naval auxiliaries are military vessels and have certain features and requirements that are not common to commercial vessels. Third, the acquisition costs may be greater for the Naval vessels because of differences in the design criteria and practices used by Navy and commercial designers. Fourth, there are differences in the inspection, quality assurance and reporting procedures that are required by the Navy and by commercial owners.

The purpose of this study was to identify and quantify the differences between Naval auxiliary and commercial vessels and then to explain why these differences existed. The reasons for the differences would be related to the first three of the four reasons why the Naval vessels may have greater acquisition costs. The differences are identified by performing several tasks. A comprehensive functional classification system is developed to facilitate the comparison of similar functions between the Naval and commercial vessels. A number of design indices are used to quantify the differences in each functional category. These design indices are also useful in assessing the impact of performance characteristics or requirements.

Two types of Naval auxiliaries were chosen for study -- fleet oilers and dry cargo replenishment vessels. These were compared to commercial tankers and break-bulk cargo vessels respectively.

CHAPTER 2

METHODOLOGY

It is the purpose of this chapter to present the criteria which governed the selection of the specific vessels that were used in this analysis and to describe the technique that was used to identify the design differences between Naval Auxiliaries and commercial vessels. The criteria that was established for the selection of vessels is discussed in section 2.1. The description of the analytical procedures is presented in section 2.2.

Section 2.1 Selection of Vessels

The objective of this analysis is to identify design differences between Naval Auxiliaries and commercial vessels. In order to be meaningful, the Naval Auxiliary types chosen had to be similar in a number of respects to the commercial vessels used in the comparison. First, while the cargo carried by the Naval Auxiliaries would not be exactly the same as that carried by the commercial vessels, it had to be at least similar in form. It would be useless to compare a commercial tanker with a Navy stores ship. Second, the vessels had to be built within the same general time frame. 1960 was selected as the cutoff year. Any vessels completed before 1960 would not be considered. Ideally it was hoped that all vessels of a particular type that were selected for use would have been built within a four year period. While it was not always possible to abide by this constraint, all of the

vessels of a certain type were built within an eight year time frame. In addition, an attempt was made to select vessels whose full load displacements were as close as possible in order to avoid design differences due only to the variance in size.

One of the biggest factors that determined which particular vessels were chosen for the analysis was the availability of design information. This information had to be obtained from a variety of sources: the U.S. Navy, the Maritime Administration, vessel owners and commercial builders. There were very few vessels for which all of the required information could be obtained. Certain information such as weight breakdowns, performance features, and cost data is considered of a proprietary nature by the Navy, the owners and builders and this required that the vessel identities be disguised.

It was not possible to obtain detailed cost information concerning any of the vessels. In a few cases, the final figure for aquisition cost was available. In discussing the cost aspects of design differences it was possible to explain only in general terms why the Naval Auxiliaries were so much more costly to build. The only cost differences that were addressed were those related to a performance difference or some peculiar aspect of the Naval vessels. No attempt was made to quantify the differences in cost which resulted from the more stringent quality assurance and data reporting practices used by the Navy, or to assess the cost impact of the Military Specification requirements on equipment.

With all of the constraints involved, combined with the availability of information, the closest match-up of Naval Auxiliary and commercial vessels possible involved comparing an ammunition ship and a combat stores ship with merchant break bulk cargo vessels and comparing a Navy oiler and a replenishment oiler with commercial tankers.

There are certain limitations of this analysis that must be mentioned. The design differences identified and discussed apply only to the vessels used in the comparison. While the Naval Auxiliaries chosen may be representative of Naval Auxiliaries in general, the commercial vessels may or may not be truly representative of commercial vessels in general. In analyzing the merchant break bulk cargo vessels, the container carrying ability was ignored in order to facilitate comparison with the Naval cargo vessels which do not carry containerized cargo. This is not thought to be a major shortcoming because these vessels were built in the early to mid 1960's as break bulk cargo vessels. The commercial tankers used in this comparison are small by today's standards but these particular vessels were selected since they were closest in size to the Navy oilers. Due to the time constraint in completing this study and due to the availability of information, a greater cross section of commercial vessels could not be included.

Section 2.2 Analytical Procedures

In order to perform a comparison between two vessels, a designer must be able to focus his attention on a particular segment of the vessels being compared and he must be assured that the comparison is

being made on common ground. Once focused on a particular segment of the vessels, the designer must be able to quantify the differences between the vessels. These two requirements spell out the capabilities that any analytical technique used in a comparitive analysis must possess. The procedure used in this study makes use of two techniques: use of a functional classification system and use of design indices.

2.2.1 Functional Classification System

In any comparative analysis it is essential that the designer divide a vessel into a number of separate functional groups. This allows the designer to focus his attention on ship features which have similar purposes. The functional classification involves assigning the applicable portion of total ship weight and volume to a functional category. A weight and volume functional classification is important because most design differences will impact the weight and/or the volume of a vessel.

The methodology used in this study was first to divide the vessels into two broad functional categories; Basic Vehicle and Useful Load. Each of these categories was then subdivided into a number of functional groups. Figure 1 displays the functional groups used in this study. Once the functional grouping were established, the procedure was to assign the applicable portion of the vessels' weight and volume to its functional group.

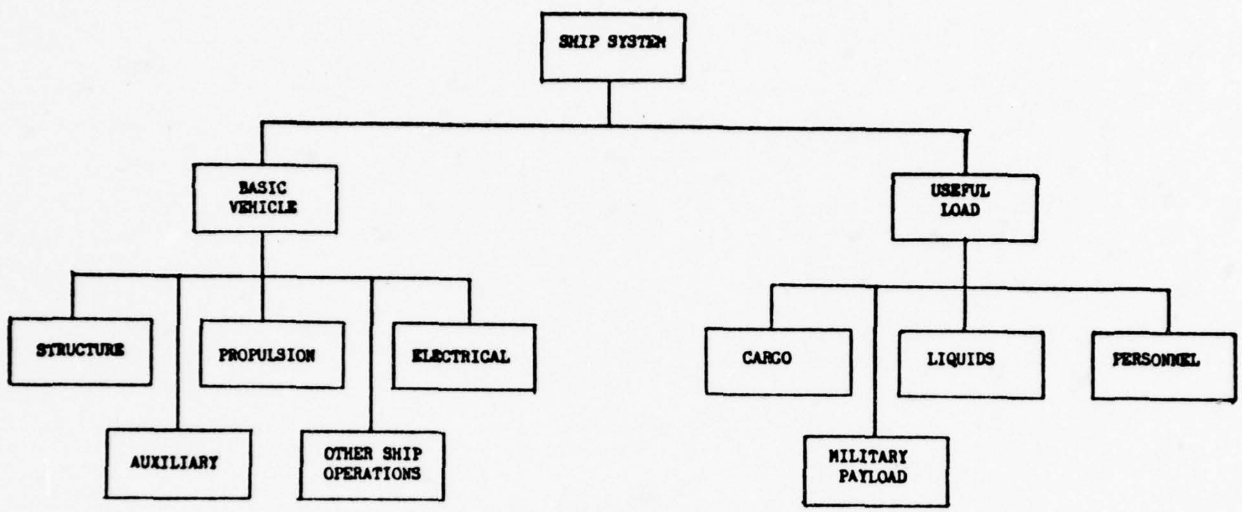


FIGURE 1 Functional Classification System

There are several weight classification systems in effect at the present time. The current Navy system is the Ship Work Breakdown Structure (SWBS) which replaced the Bureau of Ships Consolidated Index (BSCI). In addition, the Maritime Administration has its own weight classification system. The functional classification used in this analysis was developed to facilitate the comparison between Naval Auxiliaries and Commercial Vessels. The weight information obtained for a particular vessel was presented in one of three classification systems depending on whether it was a Naval or commercial vessel and whether it was a recently designed Naval Vessel or had been designed and built prior to 1974 when the BSCI system was replaced by the current SWBS system. A decision was made to convert the weight information for all the vessels to the BSCI system before subdividing the weight and assigning it to its proper functional area. This was done primarily for two reasons. First, three of the Naval Auxiliary weight statements were under the BSCI system and only one was under the SWBS system. Second, a table for conversion of construction weights from the MARAD weight classification system to the BSCI system was available.(1) A modified version of this table was used in this analysis.

In converting the SWBS and MARAD weight classifications to the BSCI system it was possible in a number of cases to find an exact correspondence between the systems. However, there were a number of cases where the correspondence was not exact and judgements had to be made as to which BSCI weight group or groups a given MARAD or SWBS weight group corresponds.

The volume classification system was based in part on the Proposed U.S. Navy Ship Space Classification Manual.[2] Under this system each compartment or space on the vessel is assigned a volume group number based on its use. The technique used in this analysis was to assign a volume grouping to each space on a vessel based on its use and then to assign this volume group to one of the functional categories. The functional categories that are used in this analysis are:

- Structure
- Main Propulsion
- Electrical
- Auxiliary
- Other Ship Operations
- Military Payload
- Cargo Payload
- Personnel
- Liquids

A detailed breakdown of the weight and volume associated with each functional category is included in Appendix B. All the weight and internal volume of each of the ships were allocated to these functions.

2.2.1.1 - Structure

The weights that comprise the structure functional category are divided into eight groups.

•hull framing, plating and inner bottom plating

•decks, platforms and flats

•structural bulkheads

•superstructures

•masts and kingposts

•doors, hatches, etc.

•foundations

•remainder (trunks and enclosures, structural castings, welding, riveting and fasteners, sea chests)

There is no volume assigned to the structure functional category since it is used to contain the volume required by the other functional groups.

2.2.1.2 - Main Propulsion

Main propulsion weight is comprised of six basic groups.

•energy generation

•propulsion unit

•propulsor

•propulsion support

•propulsion operating fluids

•propulsion repair parts

These basic groups include all main propulsion machinery, main propulsion control equipment, and main propulsion support equipment.

Main propulsion volume includes the machinery box, uptakes, and shaft alleys.

2.2.1.3 - Electrical

Electrical weight is comprised of six basic groups.

- electrical power generation
- distribution (cable)
- distribution (switchboards)
- lighting system
- repair parts
- electric power generating fluids

Electrical volume is made up of emergency generator rooms, motor generator rooms and electrical control or conversion spaces. Ship's service generators and the main switchboards are an integral part of the machinery box. As such, the volume of the machinery box occupied by this equipment is not counted with electrical volume.

2.2.1.4 - Auxiliary

Auxiliary weight is comprised of ten basic groups.

- climate control system
- sea water systems
- fresh water systems
- fuel and lubricant systems
- air, gas, and miscellaneous fluid systems
- ship control systems
- underway replenishment systems
- mechanical handling systems
- auxiliary systems repair parts
- auxiliary systems operating fluids

Auxiliary volume is comprised of six groups.

- cargo handling
- auxiliary services
- cargo offices
- cargo shops
- engineering auxiliary
- deck auxiliary

A significant portion of the auxiliary weight is located within the machinery box. The volume associated with the equipment located within the machinery box was not subtracted from the total volume of the machinery box because of the difficulty of determining the amount of volume dedicated solely to auxiliary equipment. The weight of the auxiliary equipment located in the machinery box was assigned to one of the ten basic auxiliary weight groups.

2.2.1.5 - Other Ship Operations

Other Ship Operations weight is made up of five groupings.

- control
- maintenance
- ship systems
- tankage
- aviation

Control weights include navigational systems and interior communication weights. Maintenance weights are comprised of the weights associated with storerooms, stowages and lockers, equipment for utility spaces and

workshops, and outfit and furnishings spare parts. Ship system weights are made up mainly of outfit and furnishings weights. Tankage weights are those associated with the drainage, trimming, heeling and ballast systems. Avaition weights include helicopters support equipment, and aviation stores.

Other Ship Operations volume is made up of seven groups.

- control
- maintenance
- stowage
- tankage
- passageways and access
- unassigned
- aviation

Control volume is comprised of ship control, main propulsion control and damage control spaces. Maintenance volumes are those volumes devoted to mechanical, electrical and miscellaneous shops. Stowage volumes are spaces used for stores and supplies, boats and liferafts, and motor vehicles. Tankage is comprised of ballast tanks, peak tanks, miscellaneous tanks, and voids. Aviation volumes are those spaces dedicated to storage, maintenance and support of helicopters.

2.2.1.6 - Military

Military functional weights are comprised of the following items.

- guns, mounts and launching devices
- ammunition and ammunition systems

- ordnance stores
- armament repair parts
- armament control systems
- countermeasure systems
- electronic systems including electronic countermeasures

Military functional volumes are made up of three basic groups.

- communications, detection and evaluation spaces
- weapons control, handling and storage spaces
- special missions spaces

2.2.1.7 - Cargo

Cargo weight is made up of:

- dry cargo
- refrigerated cargo
- liquid cargo

Cargo functional volume is made up of the volume devoted to stowage of dry cargo, refrigerated cargo and liquid cargo.

2.2.1.8 - Personnel

Personnel weight is broken down into three subgroups:

- living
- support
- personnel storage

Living weights are made up of furnishings for living spaces, and the load item crew and effects. Support weights are comprised of equipment for

galley, pantry, scullery and commissary outfit, and furnishings for medical and dental spaces. Personnel storage weights consist of the load items, potable water, provisions and stores and general stores.

Personnel volume is comprised of three basic groups:

- living
- support
- personnel storage

Living functional volumes are made of berthing, messing and sanitary facilities for officers and crew. Support volumes are those volumes dedicated to personnel support services such as administration, food preparation, medical and dental, personnel services and recreation and welfare spaces. Personnel storage volume is made up of space devoted to stowage of items for personnel support such as supply department personnel stores, crew storage and potable water storage.

2.2.1.9 - Liquids

Liquids functional weights are comprised of the weight devoted to the following items.

- fuel oil
- feed water
- lube oil
- miscellaneous liquids

Liquid functional volumes are those volumes needed to contain the liquid functional weights.

2.2.2 Selection of Design Indices

The use of design indices is an analytical technique which allows the design differences between vessels to be identified and quantified. In order to be useful design indices must capture the important aspects of a particular vessel. It must relate its operational performance requirements, design philosophy and design criteria/practices. There are a number of design indices which have been used successfully in the past.(3) In order to analyze the differences between Naval Auxiliary and commercial vessels selective use and modifications were made to existing design indices. There are five basic design indices used in this study.

- gross characteristics
- overall vehicle performance
- functional allocation
- specific ratios
- capacity/ship size ratios

<u>Gross Characteristics</u> describe the size and shape, speed, endurance, cargo carrying ability and any other important ship features. Examples of gross characteristics include:

- Full load displacement Δ
- Total internal volume ∇_T
- Endurance speed V_e
- Range R
- Types of cargo carried

- Type of propulsion machinery
- Crew size

An <u>overall vehicle performance</u> indice can be used to highlight the differences between a number of vessels. In general these parameters measure the cost of a particular performance characteristic. The cost may be expressed in terms of dollars or in terms of a functional capacity which must be incorporated into the design. They are used as a first step in analyzing important differences. An example of an overall vehicle performance indice is the transport efficiency, defined as follows:

$$\text{Transport efficiency} = \Delta V/SHP$$

where Δ = full load displacement

V = vehicle's speed

SHP = propulsive power required at endurance speed

A <u>functional allocation</u> is an indicator of the impact of a particular function on the whole ship. In general there are two types of functional allocations; weight fractions and volume fractions. A weight fraction is a particular functional weight divided by the full load displacement of the vessel. A volume fraction is a particular functional volume divided by the total ship volume. A comparison of functional allocations between vessels gives insight into the relative

importance of that function. Certain functional allocations can be explained as the product of two other design indices; a specific ratio and a capacity/ship size ratio. Examples of weight and volume fractions are:

- Structural weight fraction W_{ST}/Δ
- Main propulsion volume fraction V_{MP}/∇_T

A specific ratio is a design tool which provides insight to the design standards/criteria which were used in incorporating a particular feature in the design of the vessel. The specific ratio represents the "cost" of that feature divided by the "capacity" of the feature. The "cost" refers to the weight or volume impact of the characteristic. Examples of specific ratios are:

- Main propulsion specific weight ratio, W_{MP}/SHP
- Machinery box specific volume ratio, V_{MB}/SHP

The capacity/ship size ratio is the capacity of a functional category divided by the full load displacement. It gives an indication of the amount of a particular characteristic the designer is required or willing to incorporate into the ship design. Examples of capacity/ship size ratios are:

- Main propulsion capacity/ship size ratio, SHP/Δ
- Electrical capacity/ship size ratio, KW/Δ

2.2.2.1 - Structural Design Indices

The structural design indices are presented in table 1. The total impact of ship structure on full load displacement is given by the structural weight fraction. In order to assess the impact of differing structural design criteria/practices, the designer must focus his attention on those portions of the hull structure which are the primary load carrying members. For that reason the hull girder weight fraction is used. The hull girder weight fraction is comprised of the weights associated with hull framing, plating, and inner bottom plating, decks, platforms and flats, and structural bulkheads. The hull girder weight fraction can be thought of as the product of the hull girder specific weight and the hull girder volume indicator. The hull girder specific weight can be an indication of structural design criteria/practices, structural loadings and the impact of enclosed volume. The hull girder volume indicator, while not a result of structural design practice does give insight into the cost in terms of a larger structural weight fraction of having large amounts of enclosed volume.

2.2.2.2 - Main Propulsion Design Indices

The main propulsion design indices are presented in table 2. The weight and volume fractions reveal the impact of main propulsion on ship size as measured by full load displacement and total internal volume. The specific ratios can give an insight into the main propulsion design standards or criteria. They provide a means of determining the

TABLE 1

STRUCTURAL DESIGN INDICES

DEFINITION	NAME	UNITS
W_{ST}/Δ	Structural Weight Fraction	%
W_{hu}/Δ	Hull Girder Weight Fraction	%
W_{hu}/∇_{hu}	Hull Girder Specific Weight	lbs/ft^3
∇_{hu}/Δ	Hull Girder Volume Indicator	ft^3/ton

TABLE 2

MAIN PROPULSION DESIGN INDICES

DEFINITION	NAME	UNITS
W_{MP}/Δ	Main propulsion weight fraction	%
W_{MP}/SHP	Main propulsion specific weight	lbs/SHP
SHP/Δ	Propulsion capacity/size ratio	SHP/ton
V_{MP}/∇_T	Main propulsion volume fraction	%
V_{MB}/SHP	Machinery box specific volume	ft^3/SHP
W_{200}/SHP	Energy generation specific ratio	lbs/SHP
W_{201}/SHP	Propulsion generation unit specific ratio	lbs/SHP
W_{203}/SHP	Propulsor specific ratio	lbs/SHP
W_{PS}/SHP	Propulsion support specific ratio	lbs/SHP

"cost" in terms of weight and volume that the designer must pay for each increment of installed power. The capacity/ship size ratio gives an indication of the amount of shafthorsepower the designer is required to incorporate into the design to meet its performance requirements. The product of the main propulsion specific weight and the capacity/size ratio gives the main propulsion weight fraction. A further breakdown of the main propulsion specific weight is undertaken to allow the designer to focus on a particular aspect of the main propulsion system.

2.2.2.3 - Electrical Design Indices

The electrical design indices are presented in table 3. The weight and volume fractions reveal the impact of electrical systems on ship size as measured by full load displacement and total internal volume. The electrical volume fraction is not particularly revealing because it does not include the volume of the machinery box taken up by the ship's service generators. This was done deliberately because the volume impact of electrical systems on total ship size is small and because of the arbitrariness of deciding on the amount of volume to be deducted from the machinery box. The specific ratios can give an insight into the electrical design standards or criteria and allow the designer to focus on a particular aspect of the electrical design. The electrical capacity ship size ratio gives an indication of the amount of installed KW the designer is required to incorporate into the design to meet its performance requirements. The product of the electrical specific weight and the electrical capacity/size ratio gives the electrical weight fraction.

TABLE 3

ELECTRICAL DESIGN INDICES

DEFINITION	NAME	UNITS
W_E/Δ	Electrical weight fraction	%
V_E/∇_T	Electrical volume fraction	%
W_E/KW	Electrical specific weight	lbs/KW
W_{300}/KW	Electrical power generation specific weight	lbs/KW
W_{301}/KW	Power distribution (switchboards) specific weight	lbs/KW
W_{302}/KW	Power distribution (cable) specific weight	lbs/KW
W_{303}/KW	Lighting system specific weight	lbs/KW

2.2.2.4 - Auxiliary Design Indices

The auxiliary design indices are presented in Table 4. The auxiliary weight and volume fractions reveal the impact of the auxiliary functional group on total ship size as measured by full load displacement and total internal volume. Because the auxiliary functional group is composed of so many different systems with their respective weights spread out over varying amounts of volume it was felt that the specific ratios assigned to auxiliaries should employ full load displacement as the capacity of the function. Hence the units of the auxiliary specific volumes are lbs/ton. In the auxiliary functional group it is difficult to quantify a specific capacity such as SHP or KW. As such, there is no specific auxiliary capacity/ship size ratio.

2.2.2.5 - Other Ship Operations Design Indices

The Other Ship Operations design indices are presented in table 5. The auxiliary weight and volume fractions are used to reveal the impact of the Other Ship Operations on total ship size as measured by full load displacement and total internal volume. Because the Other Ship Operations functional group is composed of so many unique subsystems it was felt that the appropriate capacity would be the full load displacement. Hence the units of the Other Ship Operations functional category is lbs/ton. The volume fraction is subdivided into seven categories and six of the seven are divided by total ship volume to obtain volume fractions. The other category (unassigned volume) occupies a negligible amount of volume.

TABLE 4

AUXILIARY DESIGN INDICES

DEFINITION	NAME	UNITS
W_A/Δ	Auxiliary weight fraction	%
V_A/∇_T	Auxiliary volume fraction	%
W_{ccs}/Δ	Climate control system specific weight	lbs/ton
W_{sws}/Δ	Sea water systems specific weight	lbs/ton
W_{fws}/Δ	Fresh water systems specific weight	lbs/ton
$W_{f\&l}/\Delta$	Fuels and lubricatns system specific weight	lbs/ton
W_{ags}/Δ	Air, gas, and miscellaneous fluid system specific weight	lbs/ton
W_{scs}/Δ	Ship control systems specific weight	lbs/ton
W_{uwr}/Δ	Underway replenishment system specific weight	lbs/ton
W_{mhs}/Δ	Mechanical handling system specific weight	lbs/ton
W_{arp}/Δ	Auxiliary repair parts specific weight	lbs/ton

TABLE 5

OTHER SHIP OPERATIONS DESIGN INDICES

DEFINITION	NAME	UNITS
W_{oso}/Δ	Other ship operations weight fraction	%
V_{oso}/∇_T	Other ship operations volume fraction	%
V_{con}/∇_T	Control volume fraction	%
V_{maint}/∇_T	Maintenance volume fraction	%
V_{stow}/∇_T	Stowage volume fraction	%
V_{tank}/∇_T	Tankage volume fraction	%
V_{pass}/∇_T	Passageway and access volume fraction	%
W_{con}/Δ	Control specific weight	lbs/ton
W_{main}/Δ	Maintenance specific weight	lbs/ton
W_{ss}/Δ	Ship systems specific weight	lbs/ton
W_{av}/Δ	Aviation specific weight	lbs/ton

2.2.2.6 - Military Payload Design Indices

Table 6 displays the two military payload design indices. The Military Payload weight and volume fractions indicate the impact of the military capability on total ship size. Since military functional weights and volumes on the Naval Auxiliaries and the commercial vessels are very small, there are no specific ratios.

2.2.2.7 - Cargo Payload Design Indices

The two Cargo Payload Design Indices used in this analysis are displayed in table 7. The weight and volume fractions indicate the cargo carrying potential of each of the vessels.

2.2.2.8 - Personnel Design Indices

The Personnel Design Indices are displayed in table 8. The personnel weight and volume fractions reveal the direct impact of personnel on ship full load displacement and total ship volume respectively. The functional weights and volumes are divided into three categories; personnel living, personnel support and personnel stowage. The specific ratios are useful in determining the impact of the number of personnel on ship design. The appropriate capacity is crew size. The personnel living specific weights and volumes reveal the impact of the berthing, messing, and sanitary standards. In the same fashion, the personnel support and personnel stowage specific weights and volumes quantify the impact of the personnel support and personnel stowage functional groups on ship size.

TABLE 6

MILITARY PAYLOAD DESIGN INDICES

DEFINITION	NAME	UNITS
W_{ML}/Δ	Military payload weight fraction	%
V_{ML}/∇_T	Military payload volume fraction	%

TABLE 7

CARGO PAYLOAD DESIGN INDICES

DEFINITION	NAME	UNITS
W_C/Δ	Cargo weight fraction	%
V_C/∇_T	Cargo volume fraction	%

TABLE 8

PERSONNEL DESIGN INDICES

DEFINITION	NAME	UNITS
W_{ME}/Δ	Personnel weight fraction	%
V_{ME}/∇_T	Personnel volume fraction	%
W_{ME}/MAN	Personnel specific weight	tons/man
W_{ℓ}/MAN	Living specific weight	tons/man
W_s/MAN	Personnel support specific weight	tons/man
W_{ms}/MAN	Personnel stowage specific weight	tons/man
V_{ME}/MAN	Personnel specific volume	ft^3/man
V_{ℓ}/MAN	Living specific volume	ft^3/man
V_s/MAN	personnel support specific volume	ft^3/man
V_{ms}/MAN	Personnel stowage specific volume	ft^3/man
$MEN/\frac{\Delta}{100}$	Personnel capacity/size ratio	men/100 tons

2.2.2.9 - Liquids Design Indices

Table 9 displays the Liquids Design Indices. The weight and volume functional allocations reveal the impact of liquids on ship size. The majority of the functional allocation of liquids is required for endurance fuel oil. The fuel oil weight and volume fractions are useful in showing the effect of endurance on ship design.

TABLE 9

LIQUIDS DESIGN INDICES

DEFINITION	NAME	UNITS
W_{LI}/Δ	Liquids weight fraction	%
V_{LI}/∇_T	Liquids volume fraction	%
W_{fo}/Δ	Fuel oil weight fraction	%
V_{fo}/∇_T	Fuel oil volume fraction	%

CHAPTER 3

A COMPARATIVE ANALYSIS OF NAVAL CARGO REPLENISHMENT VESSELS AND COMMERCIAL BREAK-BULK CARGO VESSELS

The purpose of this chapter is to identify and quantify the design differences between Naval cargo replenishment vessels and commercial break-bulk cargo vessels. Wherever possible, the dollar cost impact of the design differences will be discussed. The design differences in general result from performance requirement differences, and the different design criteria or practices used by Naval and commercial designers. The analysis is conducted by first comparing the gross characteristics of the vessels and then by addressing the selected overall vehicle performance indices. A comparison of the Naval and commercial vessels is then made in each of the functional categories as discussed in Chapter 2.

The identities of the vessels had to be disguised because of the proprietary nature of the vessel characteristics and capabilities and because of the sensitive nature of certain information regarding the Naval vessels. The Naval vessels are referred to as Navy #1 and Navy #2 while the commercial cargo vessels are designated A, B, and C.

The gross characteristics of each of the vessels are discussed in Section 3.1 and the overall vehicle performance indices are compared in Section 3.2. Each functional category is analyzed individually in Section 3.3. An overall summary and the conclusions of the analysis are provided in Section 3.4.

Section 3.1 Gross Characteristics

Gross characteristics provide an overall description of the physical characteristics and the operational capabilities of a vessel. Identification of gross characteristic differences among vessels is the starting point of any comparative analysis. Many performance differences and differences in design criteria or practices between vessels are highlighted by the gross characteristic comparison. This aids the designer when performing the individual functional category analyses.

Table 10 lists the gross characteristics for each of the vessels. As can be seen there are many differences between the Naval and commercial vessels. The total internal volumes of the Naval vessels are considerably greater than those of the commercial vessels. For a given full load displacement, the Naval vessels have a greater length, wider beam, greater hull depth and less draft than the commercial vessels. All of the vessels have a single shaft steam propulsion plant but the Naval vessels have significantly greater installed horsepower. The endurance speeds are about the same but the ranges of the commercial vessels are greater.

There is a tremendous difference in the installed electrical capacity. The Naval vessels have two to three times the electrical power of the commercial vessels. There is an order of magnitude difference in crew size. The commercial vessels carry twice as much cargo by weight as the Naval vessels while there is less of a difference

TABLE 10

CARGO VESSEL GROSS CHARACTERISTICS

	Navy #1	Navy #2	A	B	C
Size					
Δ, Full load (tons)	18,589	16,100	17,210	21,053	20,959
∇_T, (ft^3)	1,982,000	1,814,000	1,124,000	1,274,000	1,298,000
Length Between Perpendiculars (ft)	540	530	470	529	514
Beam, (ft)	81	79	69	75	76
Draft, (ft)	25.8	23.84	30.1	31.5	32.0
Depth, (ft)	48.75	46.3	41.6	42.5	42.5
Main engines	1 turbine	1 turbine	1 turbine	1 turbine	1 turbine
SHP					
Commercial Rating					
Normal	--	--	10,000	16,500	12,500
Maximum	--	--	11,000	18,150	15,500
Defense	--	--	13,600	23,500	--
Naval Rating					
Cruising	18,400	11,800	--	--	--
Full Power	22,000	22,000	--	--	--

TABLE 10 (cont.)

	Navy #1	Navy #2	A	B	C
Endurance Speed V_e, (knots)	20	18.5	18	20	20
Speed at Full Power, (knots)	21	22.3	--	--	--
Range	10,000	10,000	14,400	10,870	13,410
Electric Plant	3 SSTG's, 4500 KW	3 SSTG's, 4500 KW	2 SSTG's, 1200 KW	2 SSTG's, 2500 KW	2 SSTG's, 1500 KW
	2 emergency diesel gen. 1000 KW	1 emergency diesel gen. 300 KW	1 emergency diesel gen. 100 KW	1 emergency diesel gen. 100 KW	1 emergency diesel gen. 150 KW
Complement	357	446	53	56	41
Weight of Cargo Carried (tons)	5,495	4,110	8,111	10,136	11,255
Volume of Cargo Space (ft^3)	464,000	700,000	681,000	749,000	817,000
Type Cargo Carried	Various types of ammunition	Dry provisions, refrigerated stores, fleet freight, general stores, spare parts	Break-bulk cargo, and liquid cargo	Break-bulk cargo, liquid cargo, and refrigerated cargo	Break-bulk cargo, and liquid cargo
Replenishment-at-Sea Stations	6 (3P, 3S)	6 (3P, 3S)	--	--	--

in the amount of volume devoted to cargo on each vessel. The type of cargo carried varies from vessel to vessel. The Naval vessels have an ability to transfer cargo at sea while the commercial vessels do not.

The full load displacements of the commercial cargo vessels are the displacements at the maximum allowable draft. This value for the displacement is used in calculating the design indices in the functional comparison section. The endurance speeds and ranges shown in table 10 do not correspond to this full load displacement but rather to a displacement based on a certain draft given in the ship specifications for each of the commercial vessels. The displacements at the specified drafts for each of the commercial vessels are about 10% less than the full load drafts. The full load draft was used in calculating the design indices because it gives a true measure of the cargo carrying ability of the commercial vessels and because it places the Naval and commercial vessels on common ground.

For the purposes of this analysis, the only change for the commercial vessels in going from the full load displacement to the lighter displacement is a reduction in the weight of cargo that can be carried. The lighter displacement enters the picture because of the manner in which the Maritime Administration defined sustained sea speed in the past. Sustained sea speed was the speed obtained on trial when using 80% of normal shaft horsepower at a specified draft. The endurance was then specified as the cruising radius at sustained sea speed using a certain amount of fuel oil.(5) The sustained sea speed is defined

somewhat differently by the Navy. Sustained speed for surface ships is that speed which the ship can maintain when corrected to full load displacement, normal trim, clean bottom, in deep, calm 75°F water at 80°F air at a shaft horsepower which is 80% of the design full power shaft horsepower.[6]

The speed power curves for the commercial vessels were not available and as such, the speeds that correspond to the maximum allowable shaft horsepower for commercial operations could not be obtained. It was not possible to obtain a speed power curve for the commercial vessels at full load displacement.

Many differences between the Naval and commercial vessels have been identified. The differences include not only installed capacity differences such as shaft horsepower and electrical power but also differences in hull size and form, and in cargo carrying ability. The impact of these differences will be revealed in the functional category analysis discussed in Section 3.3.

Section 3.2 Overall Vehicle Performance Indices

An overall vehicle performance indice can quantify certain capabilities of a vessel. These parameters measure the cost associated with a particular performance feature. The cost may be expressed in dollars directly or indirectly in terms of a functional capacity which must be installed in the vessel. In general the greater the functional capacity, the greater the dollar cost of that functional category. In

this analysis three overall vehicle performance indices were used:

- Transport efficiency $\Delta V/SHP$
- Speed productivity index $W_c V/\Delta$ (knots)
- Distance productivity index $W_c R/\Delta$ (miles)

The values of these parameters for each of the vessels are listed in table 11. Before comparing the performance between vessels it is necessary to explain the manner in which the individual terms of these parameters were arrived at in light of the differences in Navy and commercial practice with regards to specifying endurance and endurance speed.

The practice of the Maritime Administration at the time these commercial vessels were designed was to define sustained sea speed as the speed obtained using 80% of normal shaft horsepower while loaded to a certain draft. The required endurance was specified as the range of the vessel at sustained sea speed using a given amount of fuel oil. It was therefore necessary to use the displacement corresponding to the draft used in defining sustained sea speed. In going from the full load displacement of the commercial vessels to the slightly reduced displacement the weight of cargo that could be carried was reduced. The values of each of the parameters used in calculating the design indices are given in table 12.

The <u>transport efficiency</u> is a measure of the hydrodynamic performance of the vessels. The performance being measured is the amount of power that is required to propel a vessel of a given displacement at

TABLE 11

OVERALL VEHICLE PERFORMANCE INDICES

Vessel	$\frac{\Delta V}{SHP}$	$\frac{W_c V}{\Delta}$	$\frac{W_c R}{\Delta}$
Navy #1	20.2	5.91	2956
Navy #2	25.2	4.72	2552
A	35.4	7.59	6071
B	28.0	8.19	4452
C	30.4	9.69	6501

TABLE 12

PARAMETER VALUES USED IN CALCULATING OVERALL VEHICLE PERFORMANCE INDICES

Vessel	Δ (tons)	V (knots)	SHP	W_c (tons)	Range (R) (n.m.)
Navy #1	18,589	20	18,400	5495	10,000
Navy #2	16,100	18.5	11,800	4110	10,000
A	15,732	18	8,000	6633	14,400
B	18,487	20	13,200	7572	10,870
C	18,836	20	12,400	9132	13,410

a certain speed. The higher the value of this indice, the greater the hydrodynamic performance. As can be seen in table 11 the hydrodynamic performance of the commercial hulls at endurance speeds is greater. This is because they require less power to propel a given size vessel at its endurance speed. Less power is required due to the characteristics of the hull form. Table 13 displays the hull form characteristics for each of the vessels.

The reason for the lower hydrodynamic performance of the Naval hulls can be seen by comparing vessels B and C with Navy #1. Each of these vessels have approximately the same displacement. The Naval vessel has a greater length, wider beam and a smaller draft than the commercial vessels. In addition there are differences in the coefficients of form. The characteristics of the Naval hulls are relatively less efficient from a powering standpoint at endurance speeds. At maximum speed of the Navy ship, the Navy ship may be hydrodynamically more efficient because of the greater length.

An increase in beam will increase the resistance unless it is accompanied by a corresponding reduction in the prismatic coefficient (C_p). Navy #1 has a greater beam and a larger C_p than either vessel B or C. The commercial vessels also have a greater draft which is a relatively cheap way of obtaining displacement from a powering point of view. With the smaller midship section coefficients the Naval vessels must obtain their displacement with a longer length and full sections towards the ends.

TABLE 13

CARGO VESSEL HULL FORM CHARACTERISTICS

	Navy #1	Navy #2	A	B	C
L_{WL}(ft)	540	530	475	532	518.4
B(ft)	81	79	69	75	76
T(ft)	25.8	23.8	28	28.5	29
Δ(tons)	18,589	16,100	15,750	18,500	18,850
C_P	0.6115	0.611	0.61	.577	.586
C_B	0.577	0.564	0.60	0.569	0.577
C_M	0.9435	0.924	0.983	0.986	0.984

The less efficient hull design of the Naval vessels from a powering standpoint is not indicative of a poor design but rather is the result of tradeoffs made while the vessel was being designed. A greater beam is needed for stability and sea keeping reasons. A greater length is beneficial in terms of sea keeping, and internal arrangements for underway replenishment operations and because of the larger amount of internal volume that is required.

The <u>speed productivity index</u> indicates the speed with which a certain amount of cargo can be transported for a given size vessel as measured by the displacement. As can be seen in table 11, the Naval vessels are relatively poor performers measured against this index. In general, a low value of the speed productivity index could be the result of lower speed, less cargo carrying ability or both. With these particular Naval vessels the performance difference is due to less cargo carrying ability. The endurance speeds for all the vessels are roughly the same. Endurance speed was used in calculating this index because the commercial vessels are designed to operate at this speed. Naval practice is to specify a full power speed which corresponds to the maximum shaft horsepower than can be developed. The commercial practice at the time these vessels were designed was to specify only a sustained sea speed.

The <u>distance productivity index</u> measures the range a certain amount of cargo can be moved by a given size vessel as measured by the displacement. In general, a low value of this parameter can be the result of less endurance, less cargo carrying ability or a combination of

the two. As was the case with the other performance indices, the Naval vessels have relatively low marks. As can be seen in table 11 the distance productivity indexes of the Naval vessels are about one-half the value of those of the commercial vessels. These low marks are the result of less cargo carrying ability and less range. The greater range of the commercial vessels is not the result of carrying more endurance fuel oil. In terms of endurance miles per ton of fuel oil carried the commercial vessels again fair better.

Vessel	Endurance Miles/Ton Fuel Oil
Navy #1	3.78
Navy #2	4.52
A	7.2
B	4.94
C	5.36

Section 3.3 Functional Comparison

The total weight and volume for each of the vessels was subdivided and assigned to one of the functional groups as discussed in Chapter 2. The functional weights and volumes that were calculated for each of the vessels are listed for reference in Appendix B. The analysis of each functional category will be presented individually beginning with those groups which comprise the basic vehicle and followed by those which make up the useful load group. Each of the vessels will be analyzed at increasing levels of detail until the reasons behing the major differences in their design indices are identified.

Figures 2 and 3 are graphic respresentations of the weight and volume allocations that were computed for each of the five vessels. The numbers within each box refer to either the weight or volume fraction. The weight fraction is the weight devoted to that functional group divided by the full load displacement. The volume fraction is the volume associated with that particular group divided by the total ship volume. The height of the entire bar graph indicates the relative magnitudes of the full displacement and the total internal volume for each of the vessels.

As can be seen in figure 2 there are significant differences in the weight allocations between the Naval and commercial vessels. The most noticeable difference is the cargo weight fraction. The structural weight fractions of the Naval vessels are about 30% greater than those of the commercial vessels. The auxiliary and other ship operations weight fractions of the Naval vessels is about 15% greater. There are no significant differences in the main propulsion weight fraction. The electrical, personnel and military weight fractions of the Naval vessels are greater but their individual impact on full load displacement is small.

From figure 3 it is immediately apparent that the total internal volumes of the Naval vessels are much greater than those of the commercial vessels. There are significant differences in the auxiliary, other ship operations, and personnel categories. The main propulsion volume fractions are about the same for all the vessels but the actual

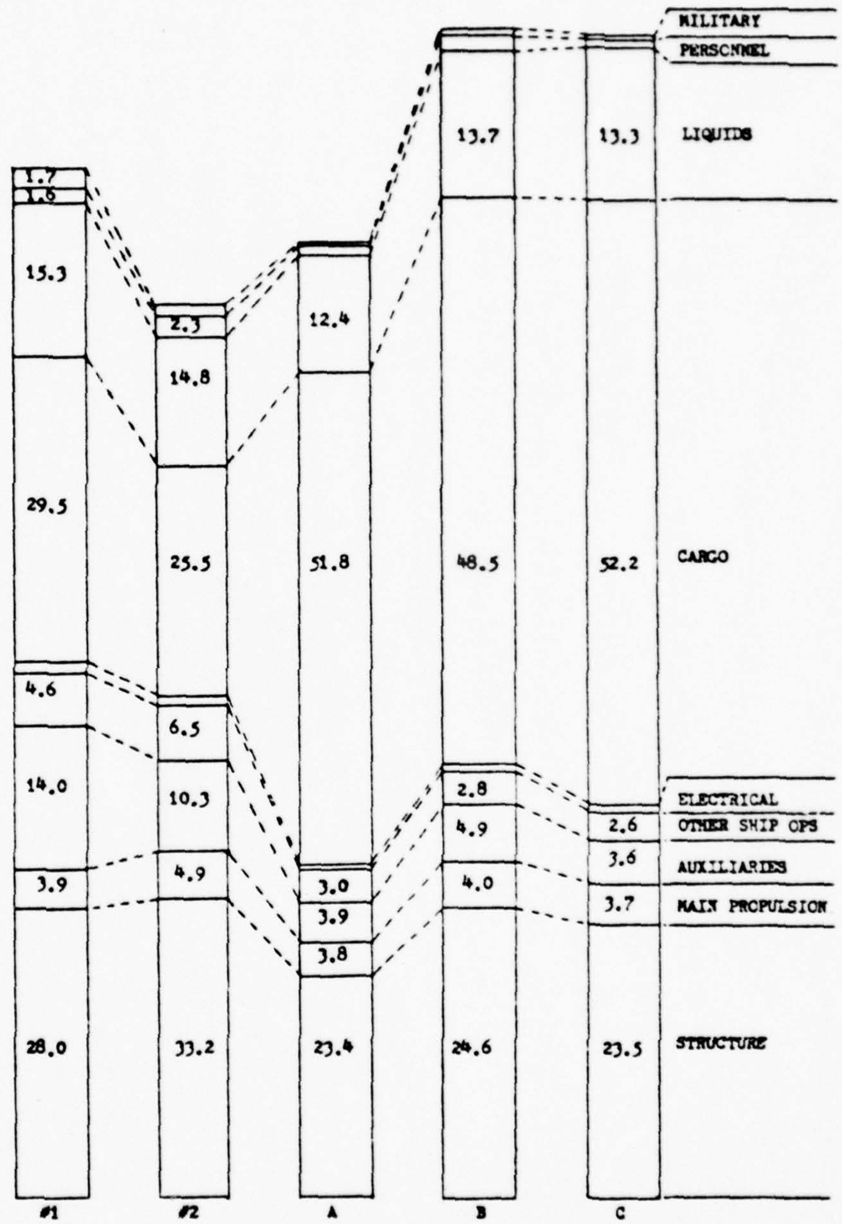


FIGURE 2 Comparison of Weight Allocations - Cargo Vessels

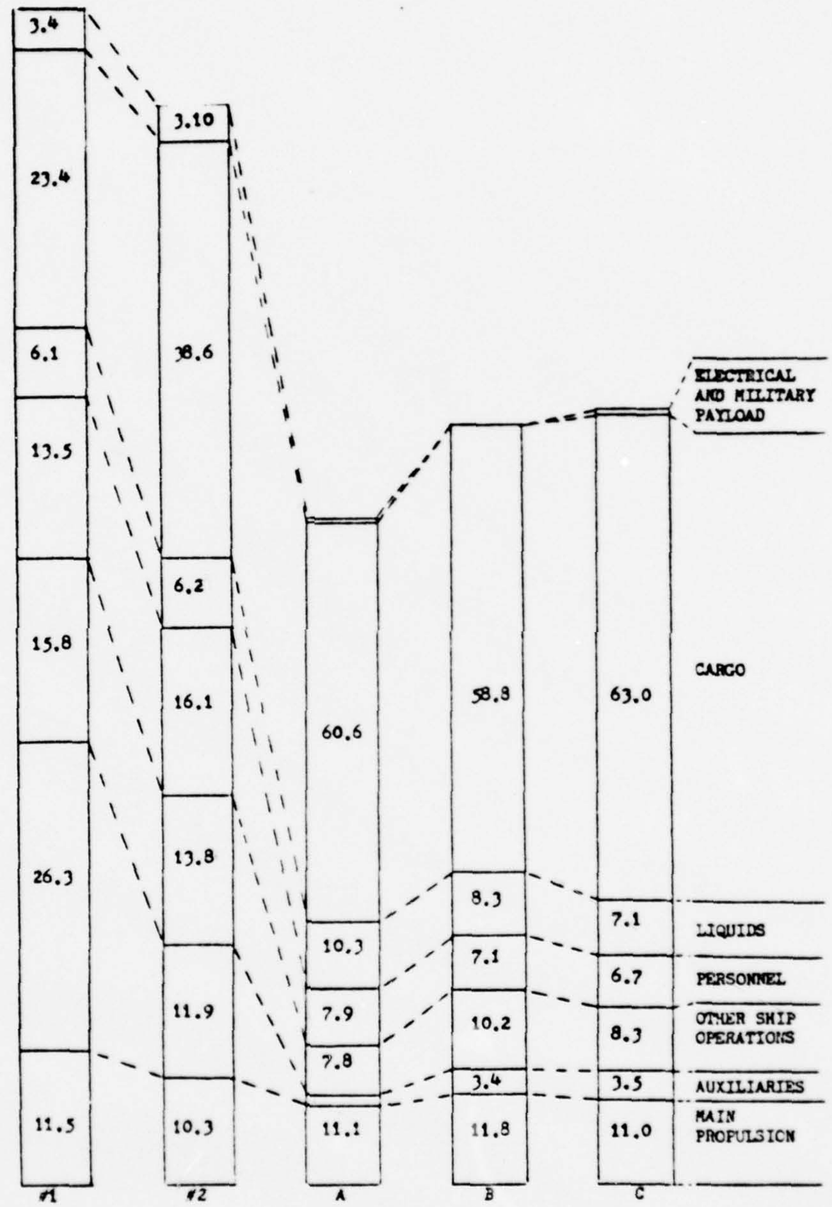


FIGURE 3 Comparison of Volume Allocations - Cargo Vessels

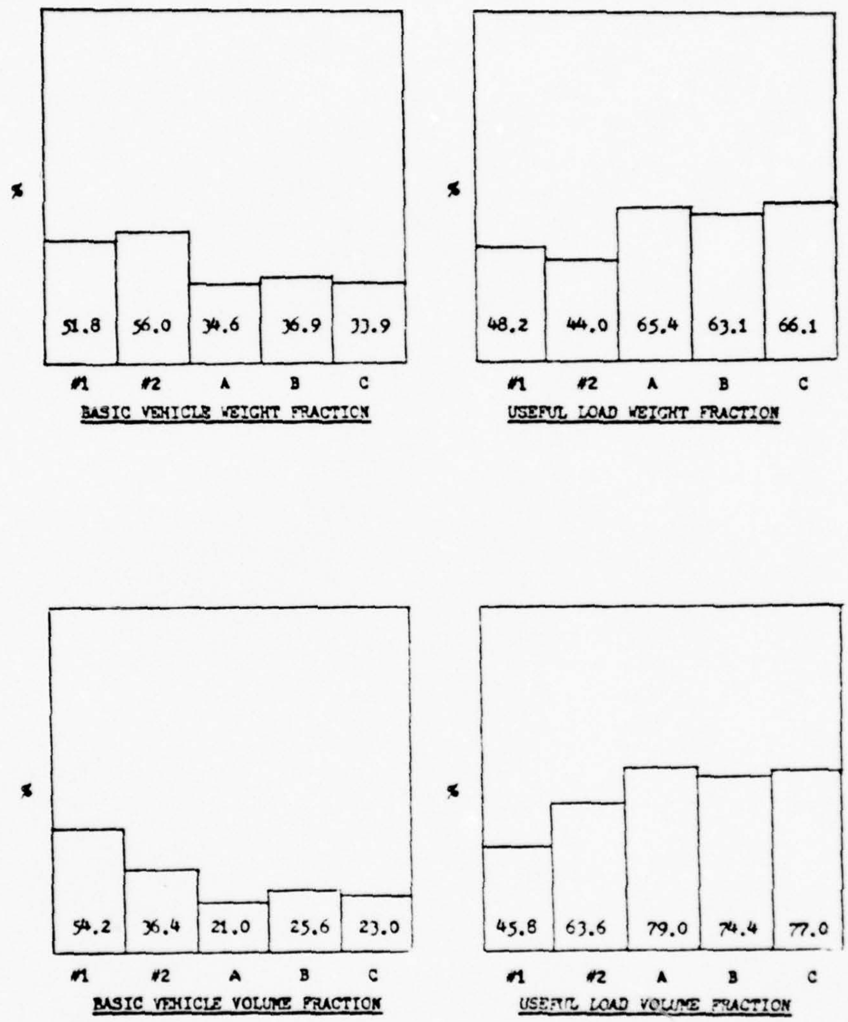


FIGURE 4 Basic Vehicle and Useful Load Weight and Volume Fractions Cargo Vessels

amount of space devoted to main propulsion on the Naval vessels is much greater. In terms of the cargo volume fraction, the commercial vessels are higher but in terms of the actual amount of volume dedicated to cargo, the difference between Naval and commercial vessels is reduced.

Figure 4 displays a graphical comparison of the basic vehicle and the useful load weight and volume fractions for each of the vessels. As can be seen, the basic vehicle weight and volume fractions of the Naval vessels are considerably greater than those of the commercial vessels. As a result, the amount of weight and volume that can be devoted to carrying out the mission of the Naval vessels is less. In the functional category analysis that follows, the reasons for the larger basic weight and volume fractions and the corresponding lower useful load weight and volume fractions will be identified.

3.3.1 Structure

The weight of structure is one of the significant differences between the Naval vessels and the commercial cargo vessels. Figure 5 is a graphical representation of the structural weight fractions. The structural weight fractions of the Naval vessels are about 30% greater than those of the commercial cargo vessels. To a first approximation, the greater the structural weight of a given vessel, the less weight that can be devoted to cargo carrying. It is important therefore to analyze why the structural weight fractions of the Naval vessels are 30% greater than those of the commercial vessels. In addition to a cargo carrying

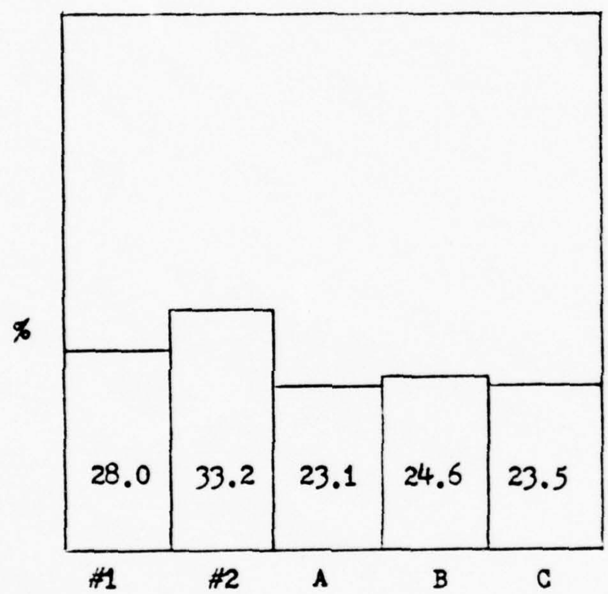


FIGURE 5 Structural Weight Fractions - Cargo Vessels

penalty, an excessively heavy structure adds to acquisition cost. Figure 6 displays a breakdown of the structural weight into the eight structural weight groups for each of the vessels. The numbers in each bar indicate the percentage of full load displacement of that portion of the structure.

In order to analyze the differences between the Naval and commercial vessels it is necessary to examine those portions of the structure which are the primary load carrying members. These members are commonly referred to as the hull girder and it is composed of hull framing, plating and inner bottom plating, decks, platforms and flats, and structural bulkheads. Figure 7 displays the hull girder weight fractions for each of the vessels. This figure has the same relative shape as figure 6 so that the deletion of the other five structural weight groups has not changed the fact that the hull girders of the Naval vessels as a percentage of full load displacement are significantly greater than those of the commercial vessels.

As can be seen in figure 7, the hull girder structural weight fractions of the Naval vessels are larger than those of the commercial vessels primarily due to the structural weight associated with decks, platforms and flats. However figure 7 does not allow the designer to assess the impact of the difference in structural design criteria/ practices and standards used by Naval and commercial designers and also figure 7 does not reveal the impact of the differences in hull configuration on structural weight. In order to gain an insight to the problem it is necessary to analyze the structural weight in greater depth.

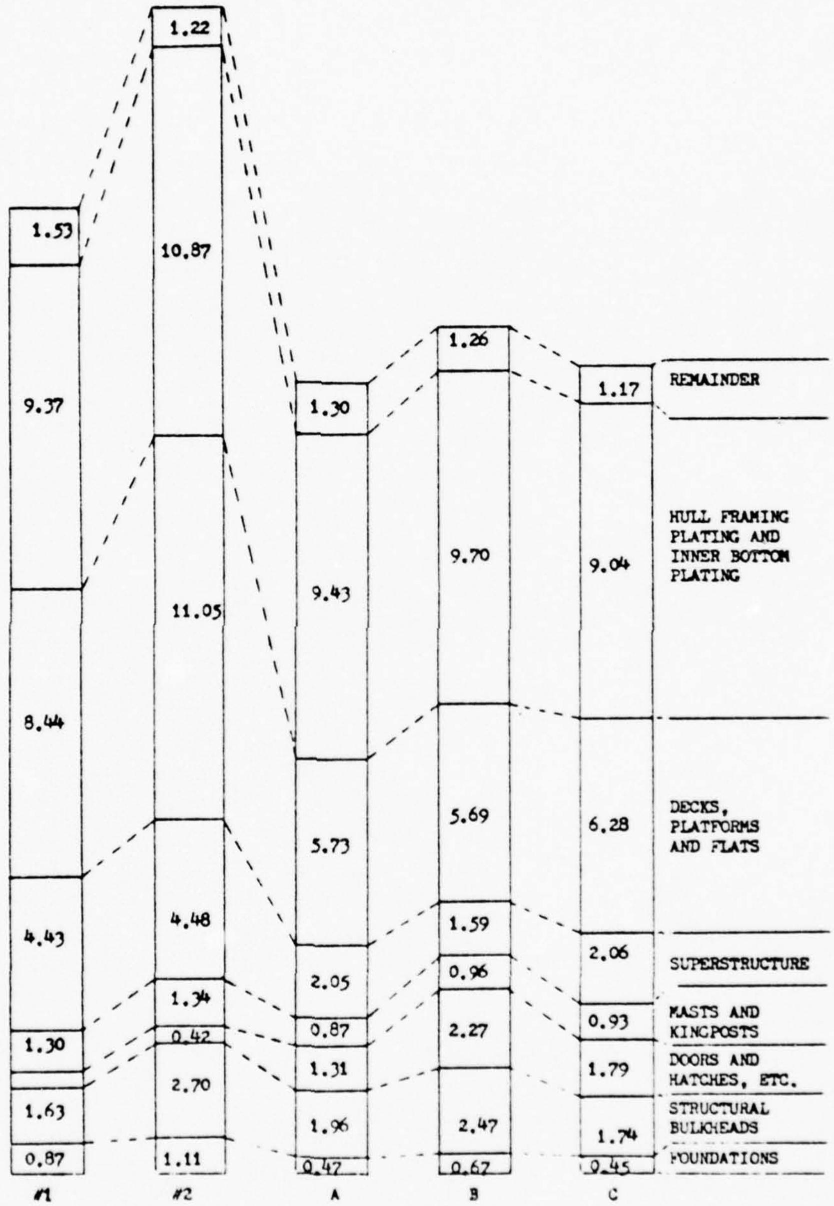


FIGURE 6 **Structural Weight Subgroups As A Percentage Of Full Load Displacement - Cargo Vessels**

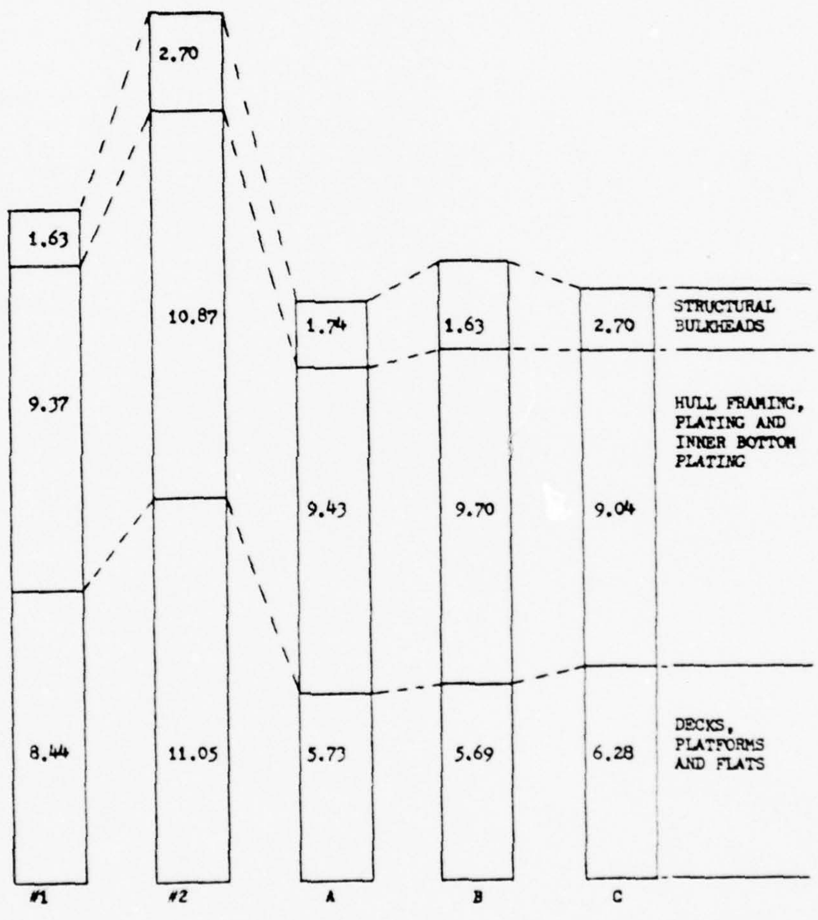


FIGURE 7 Structural Weight Of Hull Girder Elements As A Percentage Of Full Load Displacement - Cargo Vessels

The hull girder weight fraction can be explained as the product of two factors: the hull girder specific weight ratio and the hull girder size indicator. Table 14 displays the mathematics of this relationship. The hull girder specific weight is the structural weight of the hull girder divided by the volume that is enclosed by the hull girder. The hull girder size indicator in the volume enclosed by the hull girder divided by the full load displacement. In explaining the hull girder weight fraction in this manner it must be pointed out that the hull girder specific weight ratio and the hull girder size indicator are not independent of each other. There is a certain amount of coupling between the two terms. In spite of this coupling it is possible to assess the impact of differing design standards and differences in hull configuration on the hull girder structural weight fraction.

Three observations can be made from table 14. First, the hull girder weight fractions are about 25% greater for the Naval vessels. Second, the hull girder specific weight ratios of the Naval vessels are less than those of the commercial vessels. The values range from 1% less to 23% less depending on the two vessels being compared. Third, the hull girder size indicators of the Naval vessels are about 45% greater than those of the commercial vessels. The larger hull girder weight fractions of the Naval vessels can be explained by the structural specific weight and the hull girder size indicator. Each of these parameters will be addressed in sequence.

TABLE 14

CARGO VESSEL HULL GIRDER WEIGHT FRACTION EXPRESSED AS THE PRODUCT OF THE HULL GIRDER SPECIFIC WEIGHT RATIO AND THE HULL GIRDER SIZE INDICATOR

Vessel	Hull Girder Weight Fraction x 100 (%)	=	Hull Girder Specific Weight Ratio (lbs/ft^3)	x	Hull Girder Size Indicator (ft^3/ton)	x	Conversion Factor (1 ton/2240 lbs)
Navy #1	19.4		5.89		74.0		1/2240
Navy #2	24.6		6.63		83.1		1/2240
A	17.1		6.76		56.7		1/2240
B	17.9		7.61		52.6		1/2240
C	17.0		7.19		53.1		1/2240

In general there are two factors which can explain the difference in hull girder specific weight ratios between the Naval and commercial cargo vessels: First, the differences in the criteria and practices governing the structural design of the Naval and commercial cargo vessels that were in effect when these vessels were designed and built, and second, the differences in hull configuration between Naval and commercial vessels. The commercial cargo vessels were designed and built to American Bureau of Shipping Rules for Building and Classing Steel Vessels.(7) Navy structural design requirements are specified in Navy Specifications and the various Design Data Sheets.(8)(9) While both governing design procedures were based on sound engineering principles, there were certain differences between the design practices which tended to favor the Naval vessels from a weight standpoint. Structural design studies have shown that under ABS Rules and Navy structural design procedures in effect in the early 1960's, the same vessel designed to ABS Rules and to Navy standards would have a lower structural weight using the Navy's procedures.(10)

There were a number of reasons why the Naval vessels would be lighter. First, the Naval vessels in this study used a longitudinal method of framing for the hull girder while the commercial vessels used a mixed framing system (longitudinally framed bottom and inner bottom, transversely framed sides). Longitudinal framing offers a more favorable orientation of stiffened plate to resist the longitudinal bending loads. As a result, for a given level of strength, a longitudinally framed

vessel will have lighter scantlings than the same vessel framed with a transverse or combination framing system. There are several reasons why the commercial cargo vessels used in this study did not employ a longitudinal framing system. At the time these vessels were designed and built, ABS Rules did not permit reductions in plate thickness to take advantage of the greater buckling strength of longitudinally framed plating. Also the longitudinally framed sides required deep transverse frames that interfered with cargo stowage and therefore detracted from the earning power of the vessel.

In the design of decks, shell plating, and cargo deck loads, hydrostatic loads formed the basis for selection of scantlings under both ABS Rules and Navy procedures. In general the Navy gained a weight advantage by designing particular members for the anticipated loading condition whereas ABS has standardized these hydrostatic loads to a large extent.[11]

Another design difference which favored the Naval vessel from a weight standpoint was the corrosion allowance incorporated into the scantling tables of ABS Rules. The Navy has no corrosion allowance built into its design procedures. Certain areas of the hull such as the flat plate keel have corrosion allowanced added on after the required thickness is determined since this member would not be cleaned and painted as often as the remainder of the hull since it sits on the docking blocks.[12] Considering only the differences in the structural design practices of the Navy and ABS that were in effect in the early 1960's, the Naval

vessels would be expected to have a smaller structural specific weight ratio than the commercial vessels.

The hull configuration of the Naval vessels has both positive and negative effects on the structural weight as compared to that of the commercial cargo vessels. The depths of the hull girder for the Naval vessels are about 10-15% greater than those of the commercial vessels and the freeboards are about 75% greater. As the depth of the hull girder at midships is increased, the inertia of the section grows larger and it becomes possible to obtain the necessary midship section modulus with plating thicknesses in the deck and bottom that are reduced relative to a midship section requiring the same section modulus but having less depth. The result tends to be a lower structural specific weight ratio for the Naval vessels, all other aspects of hull configuration being equal. The depths of the hull girder of the Naval vessels are greater than those of the commercial vessels for a number of reasons. First, there are a number of functional volumes which require considerably more space on the Naval vessels than they do on the commercial vessels. These volumes are mainly associated with the auxiliary and other ship operations functional categories and are required to be located within the hull. Second, stability and buoyancy after damage requirements are greater for the Naval vessels and this impacts the hull depth. Third, it is advantageous to have the weather deck as high as possible to allow underway replenishment operations in greater sea states.

An aspect of hull configuration that has a large negative impact on the structural specific weight ratios of these Naval hull griders relative to those of the commercial vessels is the greater number of decks within the hull. The effect of this can be seen in figure 7 where the structural weight fractions of decks, platforms and flats are about 65% greater for the Naval vessels. The impact of decks is especially great on Naval vessel #2. Both Naval vessels have one more complete deck than the commercial hulls. The impact is greater on Naval vessel #2 because its displacement is 2500 tons less than that of vessel #1. The greater impact of decks on Navy #2 explains why its structural specific weight is significantly greater than that of Navy #1.

There is another difference in hull configuration between Naval and commercial vessels that is worthy of note. The Naval vessels have a larger number of structural bulkheads. As can be seen from figure 7, however, the structural bulkhead weight fraction does not vary significantly from Naval vessel to commercial vessel. The reason is that although the Naval vessels have a greater number of bulkheads the structural weight fraction is not significantly greater because bulkheads designed in accordance with Navy procedures are designed for the anticipated loading while the loadings under ABS Rules have been standarized to a large extent.(11)

In summary, the Navy's hull girder specific weight ratios tend to be lower because of the differences between the structural design procedures in the ABS Rules and those of the Navy which were in effect in the early

1960's, and because of the greater hull depth. The presence of the additional deck on the Naval vessels has a large negative impact on the structural specific weight especially for Naval vessel #2.

As was seen in Table 14, the hull girder size indicators of the Naval vessels are about 45% greater than those of the commercial vessels. The hull girder size indicator gives the amount of enclosed volume in a hull for a given size as measured by displacement. The Naval vessels have more enclosed volume primarily because they have a greater depth and a longer length for a given displacement. The hull girder size indicator reveals the impact of enclosed volume on the hull girder weight fraction. In order to gain sufficient deck space for all of the functions required to be within the hull, the Naval vessels are required to have an additional deck within the hull. Depending on the particular vessel, the effect of the increased volume may overshadow the weight associated with the additional deck and the structural specific weight may be lower. However, the weight of the additional deck has a large negative impact on the hull girder structural weight fraction. The larger hull girder size indicator overrides the lower specific weight ratio.

These reasons have explained why the hull girder weight fractions of the Naval vessels are larger. This fact in turn partially explains why the total structural weight fractions of the Naval vessels are larger. Other reasons why the structural weight fraction is larger are: first, the superstructure is larger, second, masts and kingposts occupy a larger portion of structural weight and third, foundation weights are greater on the Naval vessels.

The superstructure weight fractions of the Naval cargo vessels are more than twice as great as those of the commercial vessels. The reason is that the volumes of the deck house on the Naval vessels are much greater than those of the commercial vessels because of the much larger crew size, personnel support requirements and military functional volumes required in the superstructure.

The mast and kingpost weight fraction is about 40% greater on the Naval cargo vessels but the total impact on full load displacement is small. This weight fraction is greater on the Naval vessels because of the additional kingposts needed to support underway replenishment.

The foundation weight fractions of the Naval cargo vessels are about 3.5 times larger than those of the commercial tankers although the total impact on full load displacement is very small. The foundation weights are greater primarily because of the greater amount of auxiliary, electrical, command and control and armament equipment.

The weights of doors and hatches are about three times larger on the commercial vessel than on the Naval vessels because of the large hatch openings on the commercial vessels which are needed for loading and unloading operations in port. The total impact of this structural weight subgroup on ship size is small.

Hull structural costs of the Naval cargo vessels would be greater than those of the commercial vessels for a number of reasons. First, for a given full load displacement the structural weights of the Naval vessels are much greater than those of the commercial vessels in

spite of the fact that Navy structural design procedures result in a lower weight than ABS Rules. The hull girders, and the superstructures of the Naval vessels are much larger than those of the commercial vessels and the Naval vessels have a greater number of decks. Each of these translates to greater structural weight and therefore higher cost.

The differences in hull structural cost between the Naval and commercial vessels is not related only to the cost of the steel. The Naval vessels are both framed longitudinally. At the time the Naval and commercial vessels were built, longitudinal framing was not used extensively in commercial vessels. As a result, most commercial builders were probably less familar with the building of longitudinally framed vessels.[11] The labor costs involved with constructing a longitudinally framed vessel were probably higher than those associated with a transversely framed vessel. The effect, of course, would vary from builder to builder depending on his particular preferences or experience but in general, in the mid 1960's the labor cost for constructing a longitudinally framed Naval auxiliary was probably greater than that for a commercially framed commercial vessel.

In conclusion, the following statements can be made concerning the structural weights of the Naval and commercial vessels:

- The structural weights of the Naval vessels are greater primarily because the hull girder weight fractions and the superstructures of the Naval vessels are much greater. Of secondary importance are the greater weights associated with masts, kingposts, and foundations.

- The hull girder weight fractions of the Naval vessels are greater primarily because of the greater number of decks within the hull.
- The additional deck is required because of the large amount of deck space that is required within the Naval hulls.
- The detailed structural design procedures used by the Navy yielded a lower structural weight than would have been obtained if the structural design had been done in accordance with the ABS Rules that were in effect when these vessels were built.
- Hull structural costs of the Naval vessels were greater because the amount of steel in the Naval vessels was greater and because the labor costs associated with constructing a longitudinally framed vessel were greater than those of building a transversely framed vessel. This effect would vary from builder to builder.

3.3.2 Main Propulsion

The main propulsion functional area is one in which there are no significant differences between the Naval and commercial vessels from the standpoint of the weight and volume fractions. There are, however, some interesting aspects of the main propulsion function group that deserve mention. The propulsion plants installed in these Naval vessels

were basically commercial propulsion plants that were in existence at the time these Naval replenishment ships were being built. Table 15 lists the general characteristics of the propulsion plants. The Navy #2 vessel used the basic Mariner class propulsion plant.[13] When adopted for use by the Navy the rated capacity of the plant was raised since commercial practice was to be on the conservative side. To see how this impacted the main propulsion weight and volume allocations it is necessary to investigate these areas more closely. Detailed information concerning the design of the main propulsion plant of the vessel Navy #2 could not be obtained. However, during the course of completing this analysis, interviews with various people at the Naval Ship Engineering Center and the Maritime Administration have indicated that vessel Navy #2 used what was basically a commercial power plant.[13][15]

The main propulsion weight and volume fractions are displayed graphically in figure 8. The main propulsion weight fraction can be explained as the product of the main propulsion specific weight and the main propulsion capacity/ship size ratio. The mathematics of this relationship is shown in table 16. The main propulsion specific ratios are illustrated graphically in figure 9.

Two statements can be made with regards to table 16. First, the main propulsion specific weights of the Naval vessels are considerably less than those of the commercial vessels and second, the rated propulsion capacity/size ratios of the Naval vessels are much larger. Each of these points will be discussed in sequence.

TABLE 15

GENERAL CHARACTERISTICS OF THE MAIN PROPULSION PLANTS -- CARGO VESSELS

	Navy #1	Navy #2	A	B	C
SHP					
Commercial Rating					
Normal	--	--	10,000	16,500	12,500
Maximum	--	--	11,000	18,150	15,500
Defense	--	--	13,600	23,500	--
Naval Rating					
Cruising	18,400	11,800	--	--	--
Full Power	22,000	22,000	--	--	--
Type Power Plant	Turbine	Turbine	Turbine	Turbine	Turbine
Boilers					
Number	3	3	2	2	2
Suphtr outlet pres (psi)	615	615	600	600	600
Suphtr outlet temp (°F)	855	855	850	850	850
Number of Shafts	1	1	1	1	1
Propeller					
Number blades	6	4	4	4	4
Diameter (ft-in)	20-0	20-0	21-0	20-6	21-9

TABLE 15 (cont.)

	Navy #1	Navy #2	A	B	C
RPM					
Commercial Rating					
Normal	--	--	93	105	92
Maximum	--	--	96	108	98
Defense	--	--	101	118	--
Naval Rating					
Cruising	110	94	--	--	--
Full Power	115	117	--	--	--
Endurance Speed V_e (knots)	20	18.5	18	20	20
Speed at Full Power (knots)	21	22.3	--	--	--
Range	10,000	10,000	14,400	10,870	13,410

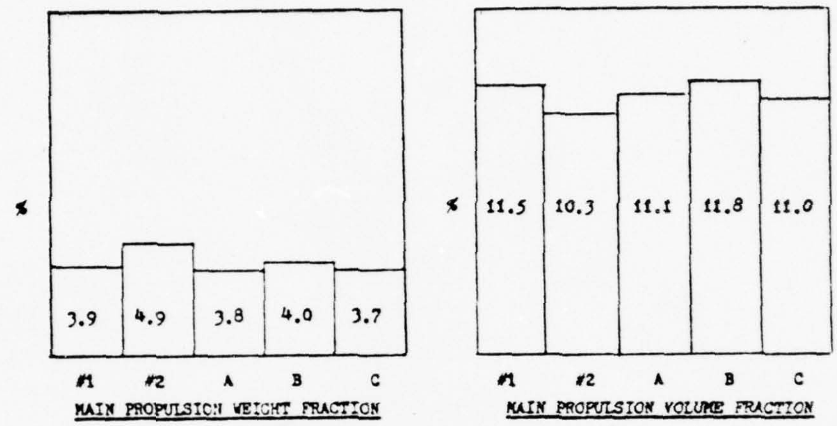


FIGURE 8 Main Propulsion Weight And Volume Fractions - Cargo Vessels

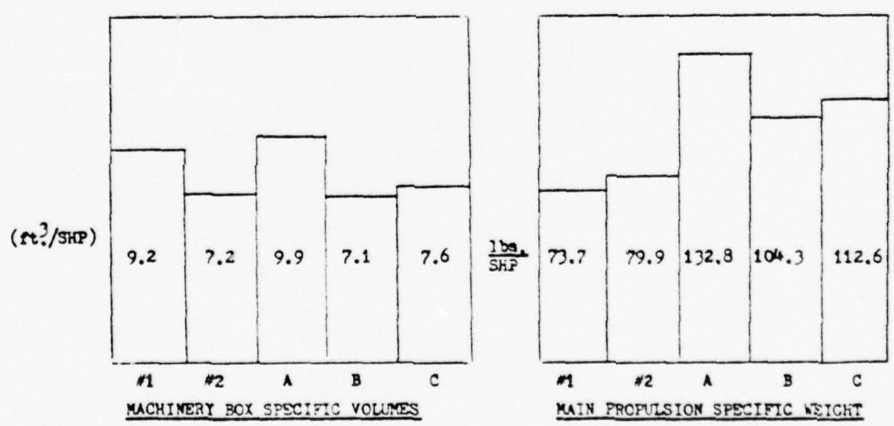


FIGURE 9 Main Propulsion Specific Ratios - Cargo Vessels

TABLE 16

CARGO VESSELS MAIN PROPULSION WEIGHT FRACTION EXPRESSED AS THE PRODUCT OF THE PROPULSION SPECIFIC WEIGHT AND THE PROPULSION CAPACITY/SHIP SIZE RATIO

Vessel	Main Propulsion Weight Fraction x 100 (%)	=	Propulsion Specific Weight (lbs/SHP)	x	Propulsion Capacity/Size Ratio (SHP/TON)	x	Conversion Factor (1 ton/2240 lbs)
Navy #1	3.89		73.68		1.18		1/2240
Navy #2	4.87		79.89		1.36		1/2240
A	3.70		132.80		0.64		1/2240
B	4.0		104.31		0.86		1/2240
C	3.72		112.59		0.74		1/2240

There are at least two reasons why the specific weights of the Naval vessels are less. The rated capacities of the Navy adopted commercial power plants are greater and there is an economy of size effect. To see the effect of the higher horsepower rating consider the Navy #2 vessel. Its propulsion plant is basically the Mariner plant which as a commercial plant had a normal rating of 17,500 SHP and a maximum rating for continuous operation of 19,250 shaft horsepower. Using the max continuous rating the main propulsion specific weight would be 91.3 lbs/SHP. When adopted for Naval use, the full power SHP was 22,000. In this case the specific ratio is 79.9 lbs/SHP. The Navy is able to achieve a smaller specific weight ratio by raising the rated power of the plant.

Using the Mariner plant to develop 22,000 SHP is not a remarkable feat. The Mariner class commercial vessels were tested during trials at 22,000 shaft horsepower. This was the first class of 20 knot cargo vessels built that would develop over 20,000 SHP with a single screw, geared turbine and as such there was a relatively large amount of excess capacity incorporated into the propulsion plant design. There are other indications of the conservative nature of commercial main propulsion design in the 1950's and early 1960's. Two of the commercial vessels in this study have defense shaft-horsepowers. Defense shaft horsepowers were a capability that was required of certain government subsidized vessels for use in wartime or national emergencies. Basically it was an extra installed capacity that could not be used during normal commercial operations. The plants were designed to provide maximum SHP for

commercial operations and the additional capacity was to be provided without a significant increase in weight of machinery and without a sacrifice in plant efficiency at normal power. In order to accomplish this, at powers above the maximum shaft horsepower for commercial operations, the following practices were permitted; sacrifice in efficiency, stresses, gear loading and pressure drops in excess of normal merchant practice and operation of certain auxiliaries normally in standby, in parallel. The plants were to be capable of continuous operation at the defense shaft horsepower. Table 15 lists the general characteristics of each of the machinery plants. As can be seen in this figure vessels A and B have defense shaft horsepowers which are significantly greater than the maximum rated shafthorsepower for commercial operations. Thus it is possible to operate these plants above their commercially rated capacity achieving greater power with no increase in weight.

The economy of size effect also helps explain why the specific weights of the Naval vessel propulsion plants are lower than those of the commercial plants. As installed horsepower is increased within certain limits, the weight of the equipment needed to generate the greater power does not increase at the same rate. The economy of size effect is separate from the higher ratings the Navy assigned to the propulsion plants. Consider the vessel Navy #2. The maximum commercial rating of this plant 19,250 shaft horsepower which is greater than the

rating of any of the other commercial power plants. The specific weight for this plant is 91.3 lbs/SHP which is also less than those of the other commercial plants.

Increasing the rated capacity of the commercial power plants helps the Navy from a weight point of view but may have had a negative effect on the amount of maintenance that was required. Many commercial owners prefer to have the machinery plant designed for maximum economy and speed at powers which are less than those that are allowed under classification society rules in part because of reduced maintenance requirements.(14) This aspect of the main propulsion design practice could not be investigated due to the scope of this study.

The propulsion plant capacity/ship size ratios are greater for the Naval vessels because the commercial propulsion plants that the Navy used for its vessels have more capacity than any of the commercial plants installed in the vessels used in this study and also because the Navy increased the rated capacity of these plants. The Navy needed propulsion plants with greater power because the endurance SHP required to propel the vessels at their endurance speeds was larger due to the relatively less efficient hull form which was discussed in section 3.2.

The main propulsion volume fractions are about three times larger than the weight fractions and the volume fractions do not vary significantly from vessel to vessel. This fact is illustrated in figure 8. The total volume of the Naval vessels for a given displacement is about 75% greater than those of the commercial vessels. Since the

main propulsion volume fractions are about the same for all the vessels, the volume of the main propulsion functional group of the Naval vessels must be relatively large. Figure 9 reveals that the machinery box specific volumes vary from vessel to vessel with neither the Naval or commercial vessels having a relative advantage. The machinery box volume is the volume of main propulsion less the volume of the stack and uptakes. It should be noted that there is no economy of size effect associated with the machinery box specific volume as there was with the specific weight. The primary reason for this is related to other functional groups in addition to main propulsion. Basically there is more equipment installed in the machinery box of the Naval vessels. For example, the Naval vessels have a greater number of electrical generators each of which is larger than any of the generators installed in the commercial vessels. In addition, the electrical generator support equipments such as condensers, air ejectors and pumps are more extensive requiring greater volume. The Naval vessels have a larger amount of auxiliary equipment such as air compressors and pumps located within the confines of the machinery box, all of which have some impact on volume.

The Naval vessels in this comparison have a third or spare boiler installed while the commercial vessels have only two boilers. The additional boiler is not needed for full power operation but is the result of a design decision to try to reduce the working hours of the boiler maintenance crews.(15) At the time these vessels were designed, the fuel oil the Navy used required so much maintenance on the boilers

that it was almost impossible to maintain a full power capability without working the crew around the clock. The addition of a spare boiler eased this problem somewhat although at the cost of greater main propulsion weight and volume.

From a dollar standpoint, the main propulsion equipment costs would be greater for the Naval vessels because they have plants which commercially would have a higher rating than any of the plants installed in the other commercial vessels. The Naval vessels also have a spare boiler installed which would add significantly to the main propulsion cost.

In summary, the following observations can be made concerning the main propulsion functional category:

- The rated capacities of the Naval vessel propulsion plants are significantly greater than those of the commercial vessels.
- This larger capacity can be explained in part by the fact that the Naval vessels used existing commercial power plants and increased the rated capacity. In addition these commercial power plants used by the Navy had a higher commercial rating than any of the power plants installed on the commercial vessels.
- The Naval vessels required a greater amount of shaft horsepower because of the relatively inefficient hull form.

- The largest impact of main propulsion is in volume. While the volume fractions do not vary much between the Naval and commercial vessels, the machinery box is much larger on the Naval vessels in terms of cubic feet. This is primarily due to the larger amount of electrical and auxiliary equipment and the presence of a spare boiler.
- The weight impact of main propulsion does not vary significantly from vessel to vessel. By increasing the rated capacity of the commercial power plants the Naval vessels were able to obtain a savings in weight. The impact on required maintenance could not be assessed although it probably would result in greater maintenance requirements.

3.3.3 Electrical

The electrical functional area is one in which there are significant differences in the design criteria and performance requirements of the Naval vessels as compared to their commercial counterparts. Table 17 lists the installed electrical capacity of each of the vessels. The electrical weight and volume fractions are displayed in figure 10. The weight impact of electrical systems on full load displacement is twice as large on the Naval vessels as it is on the commercial vessels although the total impact, even on the Naval vessels, is very small. The volume

TABLE 17

CARGO VESSELS INSTALLED ELECTRICAL CAPACITY

Vessel	Number of Generators		Capacity	Type
Navy #1	3		1500 KW	SSTG (steam)
	2		500 KW	EMERG DIESEL
		total	5500 KW	
Navy #2	3		1500 KW	SSTG (steam)
	1		300 KW	EMERG DIESEL
		total	4800 KW	
A	2		600 KW	SSTG (steam)
	1		100 KW	EMERG DIESEL
		total	1300 KW	
B	2		1250 KW	SSTG (steam)
	1		100 KW	EMERG DIESEL
		total	2600 KW	
C	2		750 KW	SSTG (steam)
	1		150 KW	EMERG DIESEL
		total	1650 KW	

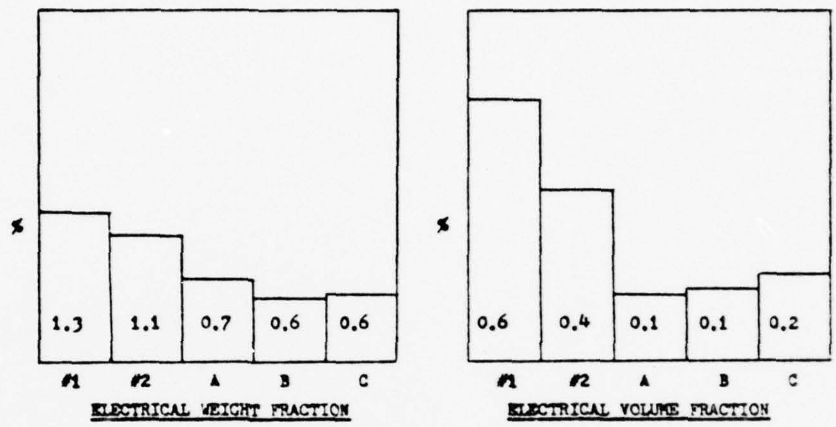


FIGURE 10 Electrical Weight and Volume Fractions - Cargo Vessels

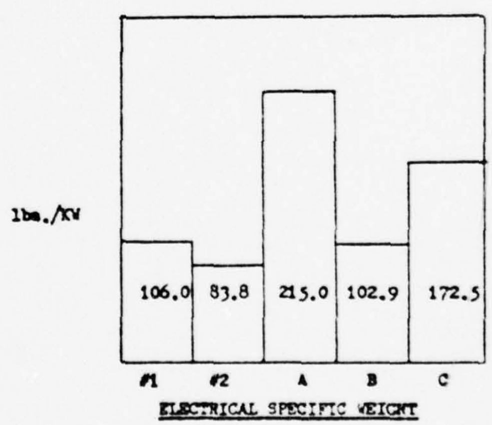


FIGURE 11 Electrical Specific Weights - Cargo Vessels

fraction is also much larger on the Naval vessels, but again the magnitude of the impact is very small. This figure is somewhat misleading in that it does not include the volume occupied by the electrical generators and associated ancillary equipment located in the machinery box. The volume in the machinery box devoted to the electrical equipment is substantial and helps explain why the machinery box volumes of the Naval Auxiliaries are so much larger than those of the commercial vessels.

The electrical weight fraction can be explained as the product of two parameters; the electrical specific weight and the electrical capacity/ship size ratio. Table 18 reveals the mathematics of this relationship. Figure 11 is a graphical representation of the electrical specific weights. With the exception of the vessel B, the electrical specific weights of the Naval vessels are much less than those of the commercial vessels. The relative magnitudes of the specific weights can be explained by an economy of size effect and the greater electrical system requirements demanded of the Naval vessels. In order to show these effects, it is necessary to subdivide the electrical specific weights into four categories:

- electrical power generation specific weight
- power distribution (switchboards) specific weight
- power distribution (cable) specific weight
- lighting system specific weight

Figure 12 displays each of specific weight subgroups. Focusing only on the cargo vessels, the relative magnitudes of each of the specific weights can be explained by an economy of size effect. Vessel B has the greatest

TABLE 18

CARGO VESSELS ELECTRICAL WEIGHT FRACTION EXPRESSED AS THE PRODUCT OF THE ELECTRICAL SPECIFIC WEIGHT AND THE ELECTRICAL CAPACITY/SHIP SIZE RATIO

Vessel	Electrical Weight Fraction x 100 (%)	=	Electrical Specific Weight (lbs/KW)	x	Electrical Capacity/Size Ratio (KW/ton)	x	Conversion Factor (1 ton/2240 lbs)
Navy #1	1.30		106.0		.274		1/2240
Navy #2	1.11		83.8		.298		1/2240
A	0.73		215.0		.075		1/2240
B	0.57		102.9		.123		1/2240
C	0.59		167.2		.078		1/2240

amount of installed electrical capacity followed by vessel C and then vessel A. Each of the electrical systems on these vessels are the same as far as numbers of generators, switchboards, cable and lighting systems. As the installed electrical power in increased, the weight of the electrical equipment increases at a slower rate. Thus the specific weight ratio would tend to decrease.

A comparison of the specific weights of the Naval and commercial vessels in figure 12 shows that an economy of size effect exists for the Naval vessels in electric power generation and lighting systems but not in the power distribution systems; switchboards and cables. The economy of size effect is missing from the power distribution (switchboard) specific weight because of the greater number of main ship service switchboards and emergency switchboards installed on the Naval vessels. There is no economy of size effect in the power distribution (cable) specific weight because the Naval vessels have a greater number of power distribution systems. The commercial vessels have two distribution systems; a normal and an emergency distribution system. The Naval vessels have four types of distribution systems:

- ship's service power distribution
- emergency power distribution
- casualty power distribution
- special power distribution

The electrical specific weights of the Naval vessels are less than those of commercial vessels A and C because of an economy of size effect. This

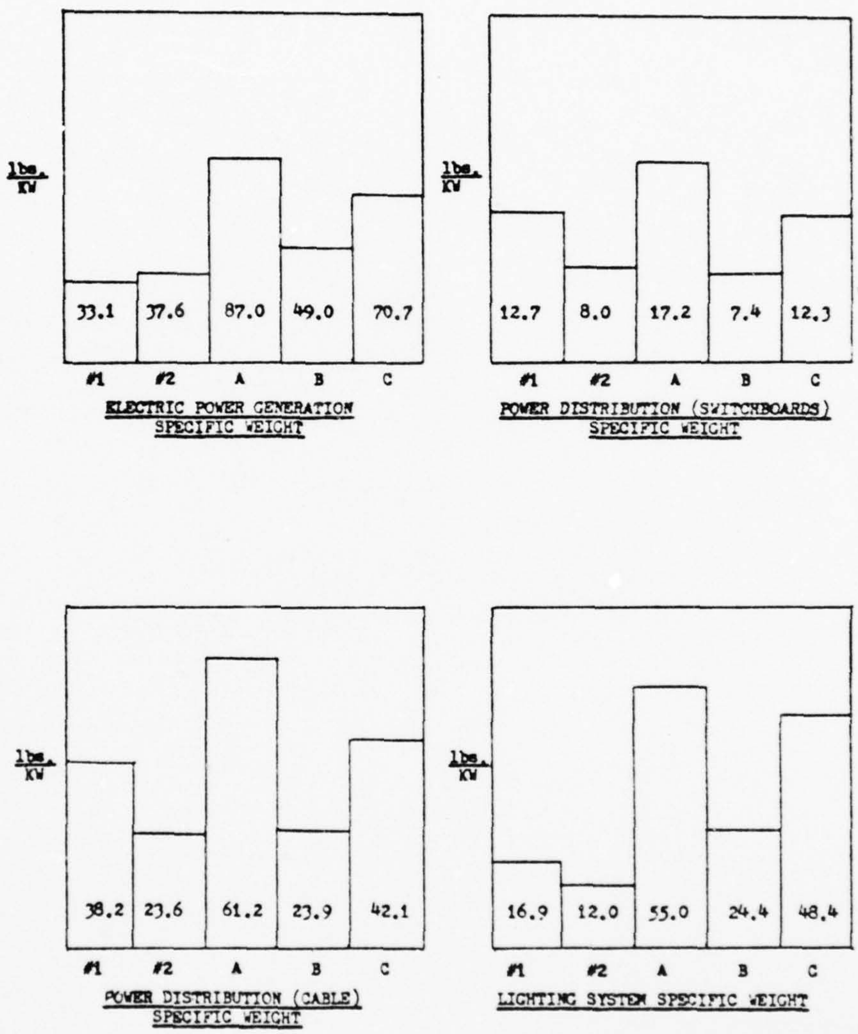


FIGURE 12 Electrical Subgroup Specific Weights - Cargo Vessels

economy of size is offset to some extent by the greater weights of the power distribution systems. Vessel B has a relative low specific weight because of its relatively large installed electrical capacity. This fact coupled with the larger distribution system weights of the Naval vessels explains why their specific weight is not considerably less than that of vessel B.

Table 18 lists the electrical capacity/ship size ratios. The ratios of the Naval vessels are about two to three times as great as those of the commercial vessels. There are two reasons why the Navy's electrical capacities are so much larger. First, the Naval vessels most demanding electrical operating condition requires about three times as much installed power as the most demanding electrical operating condition for the commercial vessels. Second, the Navy's electrical design criteria for sizing generators results in a greater installed capacity.

The Navy's most demanding electrical operating condition is during replenishment at-sea operations. The most demanding electrical operating condition for the commercial vessels is during loading and unloading operations in port. The loading/unloading operation requires about 15%-20% more electrical power than the maximum at-sea load for the commercial vessels. The in-port load of these commercial vessels is only one third that of the greatest operating condition load for the Naval vessels.

The load power analysis used by the Navy and the commercial designers to size the generators is basically the same. There are a number of operating conditions that are specified. An operating load factor is assigned for each item of equipment in each operating condition. The operating load factor is multiplied by the connected load (rated KW input) for each item of equipment in each operating condition to obtain the demand load. The total demand load for each condition of operation is found by adding the individual loads. Up to this point the Navy and commercial procedures are basically the same. To find the number of generators and their installed capacity the Navy takes the highest demand operating condition and adds a life cycle growth factor of 20%. It selects generator sizes and numbers so that this condition can be met with any one of the generators in reserve.

Commercial practice is governed by Coast Guard Electrical Engineering Regulations.[16] These regulations require that all ocean going vessels using electricity for ship's service power or light shall have at least two ship's service generating sets. The capacity of which will be such that the at-sea load can be met with one generating set in reserve. Although it is encouraged by the Maritime Administration, commercial vessels are not required to have a 20% growth factor added on to the maximum sea load before sizing the generators. As previously stated, the at-sea load is not the most demanding load for these cargo vessels.

The Naval vessels installed electrical power capacity is much larger than those of the commercial vessels because the underway replenishment condition is so demanding and because of the specific of how the Navy sizes its generators relative to commercial practice.

In terms of the dollar cost associated with the electrical system, it will be much greater for the Naval vessels for a number of reasons. First the installed electrical power is much greater. Not only are there more generators but each one is larger than any one generator on these commercial vessels. The power distribution systems, both switchboards and cables, are more extensive on the Naval vessels and therefore more expensive. Not only are costs of the additional equipments greater for the Naval vessels but the cost of the labor that is needed to install the system is greater because of its greater size and because of the greater amount of subdivision within the Naval vessels.

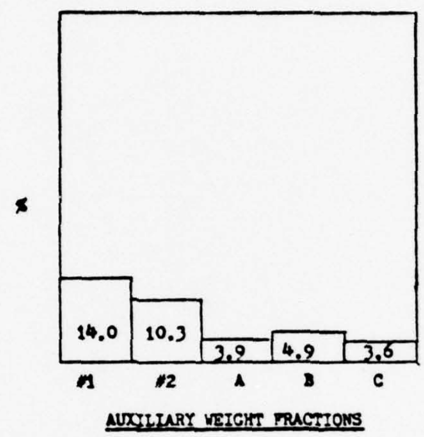
In summary, there are significant differences in the electrical functional area between the Naval and commercial vessels. The following observations can be made:

- The installed electrical capacity is a vital part of the underway replenishment capability.
- The installed electrical capacities of the Naval vessels are about three times larger than those of the commercial vessels.
- The volume impact of electrical systems is felt mainly in the size of the machinery box that is required.

- The Naval vessels are required to have more elaborate power distribution systems in terms of more switchboards and a greater number of cable systems.
- There are minor differences in the criteria for sizing generators between the Naval and commercial vessels. Naval practice is that there be sufficient generator capacity to supply the KW required for the greatest electrical operating condition with any one of the generators in reserve. Commercial practice calls for the at-sea load to be handled with one generator in reserve. On these vessels the at-sea electrical load is not the most demanding.
- The dollar cost of the electrical functional category will be greater for the Naval vessels because of the large electrical power required, the more extensive distribution systems and the greater amount of labor needed to install the system.

3.3.4 Auxiliary

The auxiliary functional group has a considerably greater impact on the Naval vessels than on the commercial vessels. Figure 13 displays the auxiliary weight and volume fractions. The weight impact of the auxiliary functional group on full load displacement is twice as great on the Naval vessel. The auxiliary functional volume has a greater impact



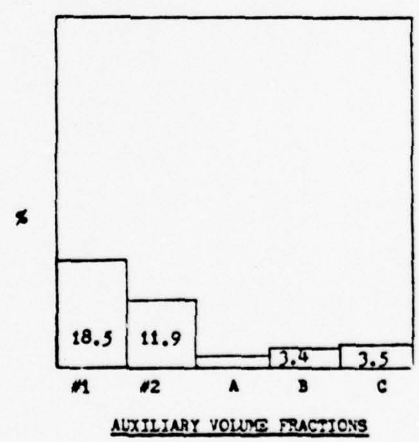


FIGURE 13 Auxiliary Weight And Volume Fractions - Cargo Vessels

on ship size than the weight impact. The auxiliary volume fractions on the Naval vessels are considerably greater than those of the commercial vessels.

The auxiliary functional volume is comprised of five volume subgroups:

- cargo handling
- auxiliary services
- cargo offices and shops
- auxiliary systems and equipment
- deck auxiliaries

Auxiliary services and cargo offices and shops have negligible volume impact. Figure 14 displays the volume fractions of the remaining three auxiliary volume subgroups. The deck auxiliary volume fractions do not vary by much from vessel to vessel. The auxiliary services volume fractions are only slightly larger for the Naval vessels. The reason for the slight difference is the larger ventilation and air conditioning systems which are the result of the increased compartmentation and larger crew size of the Naval vessels.

It is the cargo handling volume which accounts for the much larger impact of the auxiliary volume on the Naval vessels. The volume devoted to cargo handling is necessary on the Naval vessels to support the underway replenishment capability. A large amount of space is needed to allow the cargo that is to be transferred at sea to be sorted and staged prior to the underway replenishment. The handling space is large enough

FIGURE 14 Auxiliary Subgroup Volume Fractions - Cargo Vessels

so that the cargo destined for more than one vessel can be staged ahead of time. It must also be large enough to allow fork-lift trucks to operate efficiently. The cargo handling volume also includes the volume devoted to the numerous elevators which are installed to facilitate rapid movement of cargo from the cargo holds to the staging areas.

In order to determine the reason for the larger auxiliary weight fractions on the Naval vessels it is necessary to subdivide the auxiliary functional weight into the following nine categories:

- climate control system
- sea water systems
- fresh water systems
- fuels and lubricants systems
- air, gas and miscellaneous fluids
- ship control systems
- underway replenishment systems
- mechanical handling systems
- auxiliary repair parts

The weights of these subgroups are divided by the full load displacement to obtain specific weights. The units are lbs/ton. Table 19 lists the values of these specific weights. There are no significant differences between the fresh water systems specific weights and the fuels and lubricants systems specific weight of the Naval and commercial vessels as can be seen in table 19.

TABLE 19

AUXILIARY SPECIFIC WEIGHTS -- CARGO VESSELS

Parameter	Units	Navy #1	Navy #2	A	B	C
Underway Replenishment System Specific Weight	lbs/ton	201.0	63.9	18.6	23.6	19.4
Climate Control System Specific Weight	lbs/ton	20.2	79.6	16.9	35.6	14.8
Mechanical Handling System Specific Weight	lbs/ton	16.2	18.1	13.4	13.9	13.5
Sea Water Systems Specific Weight	lbs/ton	13.8	12.8	10.3	8.3	5.4
Ship Control Systems Specific Weight	lbs/ton	10.6	9.3	4.7	5.4	4.9
Fresh Water System Specific Weight	lbs/ton	9.9	9.9	10.9	8.9	8.4
Fuels and Lubricants Specific Weight	lbs/ton	8.7	9.8	10.2	9.7	10.3
Air, Gas and Misc. Fluid Specific Weight	lbs/ton	6.2	6.1	2.2	2.7	2.0
Auxiliary Repair Parts Specific Weight	lbs/ton	3.05	2.81	0.1	0.1	0.1

The underway replenishment system specific weights of the Naval vessels account for the majority of the total difference in the auxiliary functional weights between the Naval and commercial vessels. This subgroup is made up of the weights of the elevators, and the cargo handling equipment needed for underway replenishment operations. This equipment is not carried by the commercial vessels. The exceptionally large value of the underway replenishment system specific weight for the Navy #1 vessel is due to the nature of the cargo. There is a substantial amount of cargo ammunition handling equipment required.

The climate control system specific weights of Navy #2 and vessel B are the largest primarily because they carry refrigerated cargo and need larger refrigeration plants. The other vessels do not carry refrigerated cargo. The impact of climate control is greater on Navy #1 than on vessel B because a larger percentage of its cargo is devoted to refrigerated cargo. This subgroup has the largest impact on the auxiliary specific weight of vessel Navy #2.

The mechanical handling system specific weights of the Naval vessels are about 25% greater than those of the commercial vessels. This weight group is made up of winches, capstans, cranes and anchor handling equipment. The difference in specific weight is traceable to the larger number of winches installed on the naval vessels. These are needed to support the underway replenishment capability.

The sea water systems specific weights of the naval vessels are also greater. Sea water system weights are made up of the following groups:

- drainage, trimming, heel and ballast systems
- firemains, flushing, sprinklers and salt water service systems
- plumbing and deck drains (50%)

The larger firemains, flushing, sprinklers and salt water service systems of the Naval vessels account for the larger specific weight. This reflects primarily the Navy's greater emphasis on damage control, the requirement for ammunition magazine sprinkler systems and the larger crew size.

The ship control specific weights are about twice as large as those of the commercial vessels. The ship control system weight is made up of the steering gear system and the rudder. The difference in the ship control specific weight is due to the larger rudder weight of the Naval auxiliaries. The rudder weight is larger because the rudder on the Naval vessels is larger than that used in normal commercial practice in order to increase the maneuverability of the vessel during in close replenishment operations.

The Naval vessels' air, gas and miscellaneous fluid system specific weights are about three times as great as those of the commercial vessels although the magnitude of this specific weight is relatively small. The air, gas, and miscellaneous fluid system is made up of the following weight groups:

- Gas, HEAF, cargo piping, O_2-N_2, aviation lube oil systems (20%)
- Fire extinguishing systems

•Compressed air systems

•Miscellaneous piping systems

The majority of the difference in this specific weight is due to the larger compressed air system on the Naval vessels. HP compressed air is needed to carry out underway replenishment operations.

The Navy also carries a greater amount of spare parts to support the auxiliary equipment. The difference in specific weight of this subgroup is of secondary importance.

From a cost standpoint the auxiliary functional group would be more expensive for the naval vessels than for the commercial vessels. The subsystems which make up the auxiliary functional groups on the Naval vessels are more extensive and have greater capability than those installed on the commercial vessels primarily in order to support underway replenishment operations. In addition to the individual subsystems being larger and therefore more costly, the labor costs of installing these systems is greater.

In summary, the following observations can be made concerning the auxiliary category.

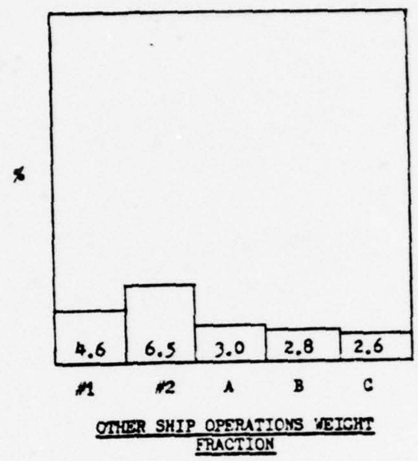
•The weight and volume impact of the auxiliary functional group is greater on the Naval vessels.

•The auxiliary volume requirement is the largest factor which contributes to the difference in total ship volume between the Naval and commercial vessels.

- The impact of auxiliary volume is so great because of the amount of space dedicated to cargo handling. The Naval cargo replenishment vessels need access to, and efficient movement and staging of cargo prior to transferring it to another vessel.
- The auxiliary weight fractions of the Naval vessels are about three times as large as those of the commercial vessels. The differences in weight are due primarily to those subsystems which give the Naval vessels the ability to transfer cargo at sea. These subsystems are the transfer equipment, mechanical handling equipment, the HP air system and the larger ship control system.
- From a cost standpoint, the auxiliary functional group is more expensive for the Naval vessels because the individual subsystems are more extensive or unique to the Naval vessels.

3.3.5 Other Ship Operations

Other ship operations is another area in which the impact on the Naval vessels is greater than that on the commercial vessels. Figure 15 displays the other ship operations weight and volume fractions. Both the weight and volume impacts of other ship operations are greater on the Naval vessels. The largest impact of other ship operations on ship size is in terms of volume.



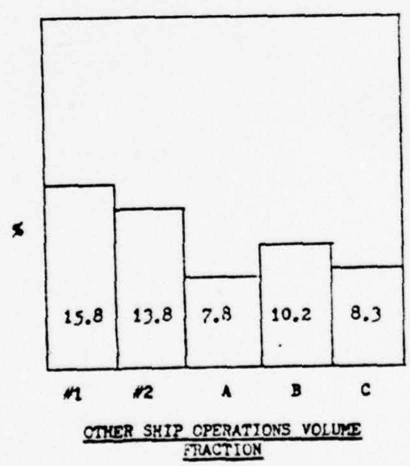


FIGURE 15 Other Ship Operations Weight And Volume Fractions - Cargo Vessels

The other ship operations functional volume is made up of seven groups:

- •control
- •maintenance
- •stowage
- •tankage
- •passageways and access
- •unassigned and temporarily unclassified
- •aviation

Figure 16 is a graphical presentation of the volume fractions of each of these subgroups. The unassigned and temporarily unclassified volumes are either zero or of negligible value for each of these vessels.

As can be seen in figure 16, the primary differences in the other ship operations volume fractions between the Naval and commercial vessels are due to maintenance, passageways and access, and aviation volume fractions. The tankage volume is larger on the commercial vessels. The control volume fraction is slightly larger on the Naval vessesl and the stowage volume fraction is about the same on all the vessels.

The maintenance volume fractions are larger for the Naval vessels. Maintenance volume is composed of mechanical maintenance spaces, electrical maintenance spaces and general workshops. The Naval vessels allot more volume to each of these functional volumes. This reflects the different maintenance practices between the Naval and commercial vessels. More elaborate maintenance facilities are required in order to support the underway replenishment capability and the military capabilities of the Naval vessels.

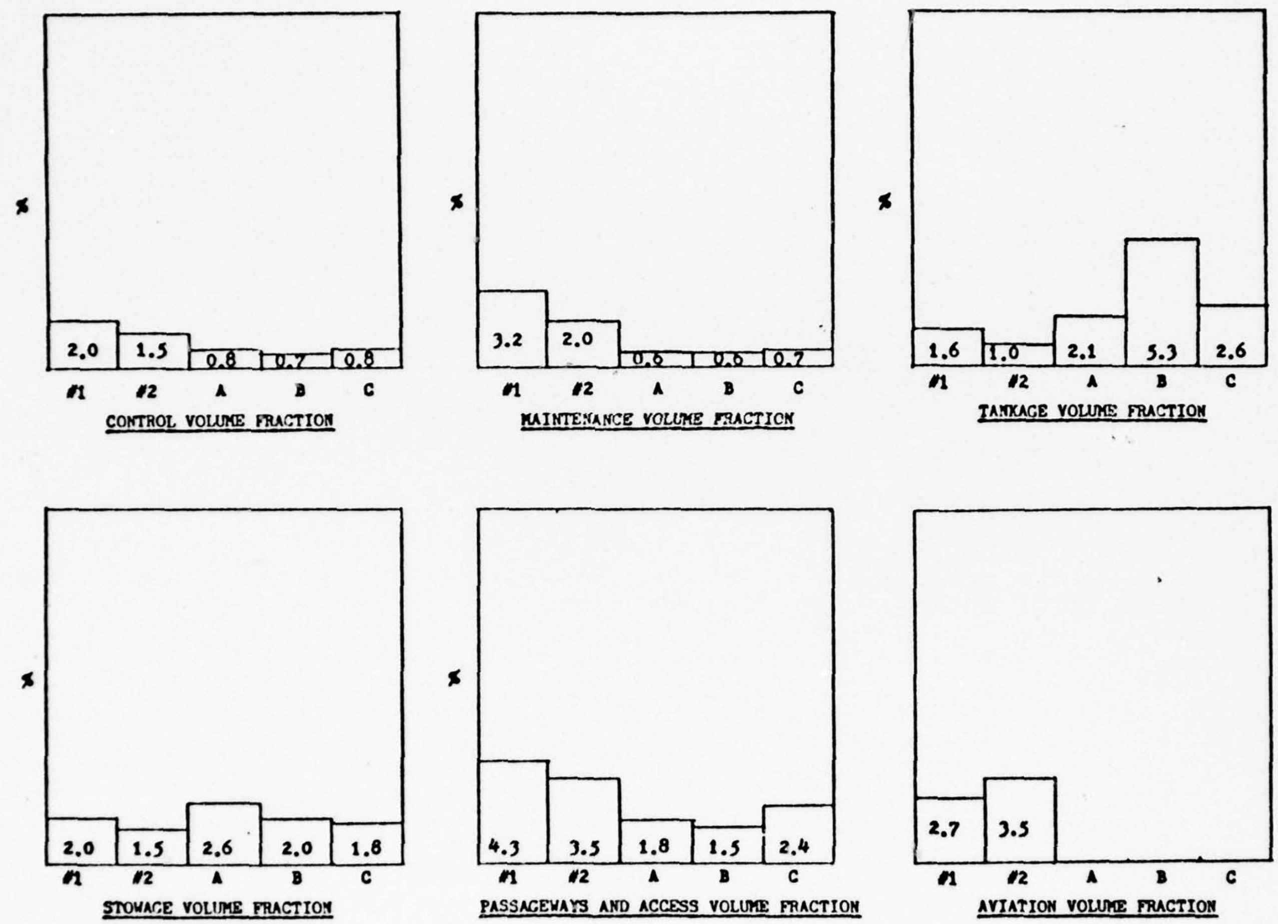


FIGURE 16 Other Ship Operations Subgroup Volume Fractions - Cargo Vessels

The passageway and access volume fraction is larger on the Naval vessels primarily because of the larger amount of subdivision within the hull and the superstructure which results from the larger crew size and the larger number of different functions that are needed to support the crew and the ship's mission.

There are no aviation related spaces on the commercial vessels. The majority of the aviation volume on the Naval vessels is made up of the helicopter hanger. The helicopters are used for vertical replenishment at sea (VERTREP).

The tankage volume fractions are larger for the commercial vessels. The reason is due to the fact that the merchant vessels have tankage dedicated specifically to salt water ballast in addition to using empty fuel oil tanks. These are necessary for trim, stability or seakeeping reasons in the light load condition.

In order to identify the causes of the differences in the other ship operations weight fraction between the Naval and commercial vessels it is necessary to subdivide the other ship operations weight into the following four groups.

- control
- maintenance
- ship systems
- aviation

When the weight of each of these subgroups is divided by the full load displacement the result is a specific weight. Table 20 lists the specific weights for each of these groups. Each of these will be addressed separately.

TABLE 20

OTHER SHIP OPERATIONS SPECIFIC WEIGHTS -- CARGO VESSELS

Parameter	Units	Navy #1	Navy #2	A	B	C
Control Specific Weight	lbs/ton	5.0	3.9	1.9	2.1	1.3
Maintenance Specific Weight	lbs/ton	18.6	73.7	9.5	10.0	5.1
Ship Systems Specific Weight	lbs/ton	71.0	56.2	55.6	50.8	51.5
Aviation Specific Weight	lbs/ton	8.9	11.1	0	0	0

The control specific weights are about twice as large for the Naval vessels as for the commercial vessels. Control weight is comprised of the following subgroups.

- navigation systems and equipment
- interior communications systems
- furnishings for electronics and radar spaces

The larger control specific weights are the result of the weight associated with the interior communications system and the furnishings for electronics and radar spaces. These are related primarily to the military payload and functions that are carried by the Naval vessels.

Maintenance specific weights are much larger for the Naval vessels with Navy #2's being exceptionally large. Maintenance weight is divided into four subgroups.

- storerooms, stowages and lockers
- equipment for utility spaces
- equipment for workshops
- outfit and furnishings spare parts

Navy #2's specific weight is so large because of the amount of weight devoted to storerooms, stowages and lockers. This is necessary because of the nature of the cargo carried by this vessel. It carries many different stock items which must be stored separately in cabinets, bins or on shelves and they must be readily accessible so that supply orders may be filled rapidly. The Naval vessels also have a greater amount of weight in each of the other subgroups. These weights reflect the additional support requirements that are needed on the Naval vessels because of the underway replenishment capability.

Ship system specific weights are about the same for all the vessels except for that of Navy #1's which is about 30% greater. Ship systems is divided into the following categories.

- •hull fittings
- •boats, stowage and handling
- •rigging and canvas
- •ladders and gratings
- •non-structural bulkheads
- •painting
- •deck covering
- •hull insulation

Navy #1's specific weight is relatively large because of the amount of deck covering and hull insulation that is installed. This is related to the nature of the cargo carried and it is needed for safety reasons and climate control. There are no significant differences in any of the other weight subgroups.

The commercial cargo vessels have no helicopter facilities or support equipment. As such their aviation specific weight is zero. The aviation weights on the Naval vessels are made of the weight of the helicopters, helo stores and helo fuel. The helicopters are carried to enhance the replenishment-at-sea capability.

From a cost viewpoint, other ship operations has a greater impact on the acquisition cost of the Naval vessels than on the commercial vessels for the same primary reason that costs associated with main

propulsion, electrical and auxiliary are greater on the Naval vessels. Basically performance "costs". In the other ship operations category it is impossible to quantify a level of performance or an installed capacity such as installed horsepower (SHP), or installed electrical power (KW). However, each of the weight subgroups which make up the other ship operations category for the Naval vessels are larger than those of their commercial counterparts because of some additional capability or unique requirement which is necessary to support the underway replenishment capability or the military payload of the Naval vessel.

The greater volume required by the other ship operations functional category has an impact on vessel cost in the sense that the large volume forces the total volume of the vessel to be larger which then impacts the cost associated with the structural functional group.

In summary, the following observations can be made concerning the other ship operations category.

- The weight and volume impact of the other ship operations functional category is significantly greater on the Naval vessels. The largest impact of other ship operations is in the volume required.
- The volume devoted to other ship operations accounts for a substantial portion of the internal volume differences between the Naval and commercial vessels.

- The other ship operations functional volume is greater on the Naval auxiliaries due to the amount of space devoted to maintenance facilities, passageways and access and aviation facilities. Maintenance volumes are greater because of the necessity of having on-board repair facilities that would permit extended operations at sea. Passageways and access volumes are greater because of the larger amount of subdivision in the hull and superstructure. Aviation volumes are unique to the Naval vessels. The aviation capability is an integral part of the replenishment at sea capability.
- The weight impact of other ship operations is also greater on the Naval vessels. This is due primarily to the amount of weight associated with maintenance and aviation facilities. Control and ship systems weights are also larger. The larger other ship operations weight fractions reflect the amount of support needed for the underway replenishment capability.

3.3.6 Military Payload

The military payload area is one which has a greater impact on the Naval vessels than on the commercial vessels although the total impact on the Naval vessels is very small. The Naval auxiliaries have

weapons systems installed for defensive purposes only. Figure 17 displays the military payload weight and volume fractions.

Military payload weight is composed of the following groups.

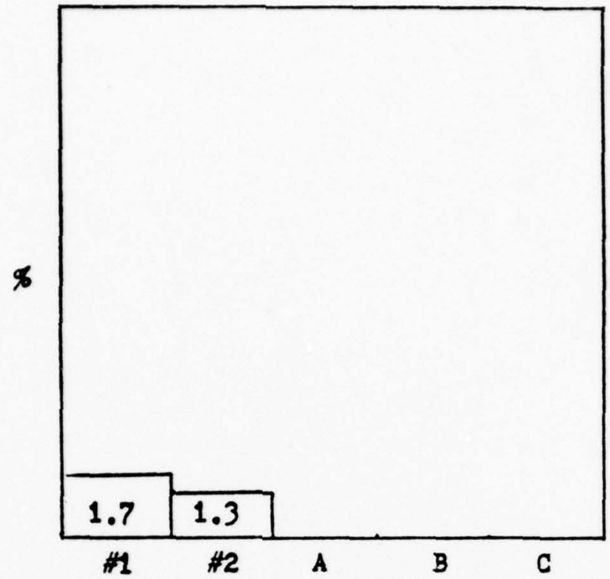
- guns, mounts and launching devices
- ammunition and ammunition handling systems
- ordnance stores
- armament control system
- countermeasure systems (non-electronic)
- electronic systems including electronic countermeasures

The Naval vessels have weights associated with each of the subsystems while the only military payload items installed on the commercial vessels would be the radio communications, storage batteries, and electronic navigating equipment. The weight associated with the commercial vessels is negligible. The Naval vessels have a more extensive communications and electronics suit and both Naval vessels have four twin 3"/50 caliber gun mounts and their associated ammunition handling and stowage systems.

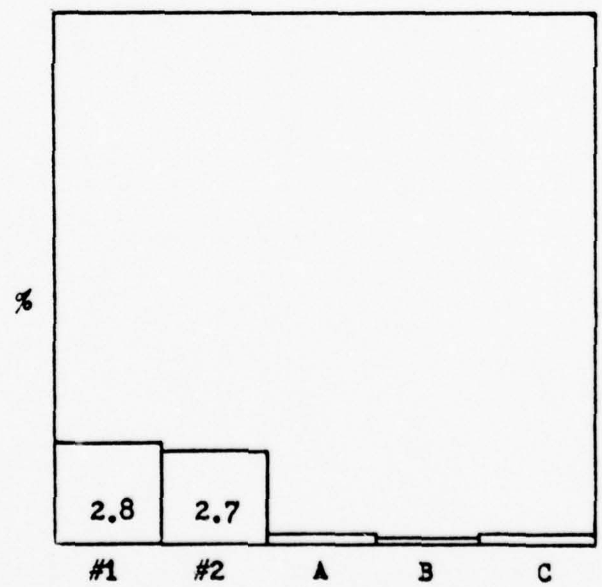
Military payload volume is made up of three subgroups.

- communications, detection and evaluation
- weapons spaces
- special mission spaces

The volume impact of military payload is almost negligible on the commercial vessels. The only military payload volume is the volume of the communication spaces. The volume impact of military payload is



MILITARY PAYLOAD WEIGHT FRACTION



MILITARY PAYLOAD VOLUME FRACTION

FIGURE 17 Military Payload Weight And Volume Fractions - Cargo Vessels

small compared to the impact of some of the other functional groups. The larger military payload volumes on the Naval vessels are the result of weapons control and ammunition handling and stowage facilities.

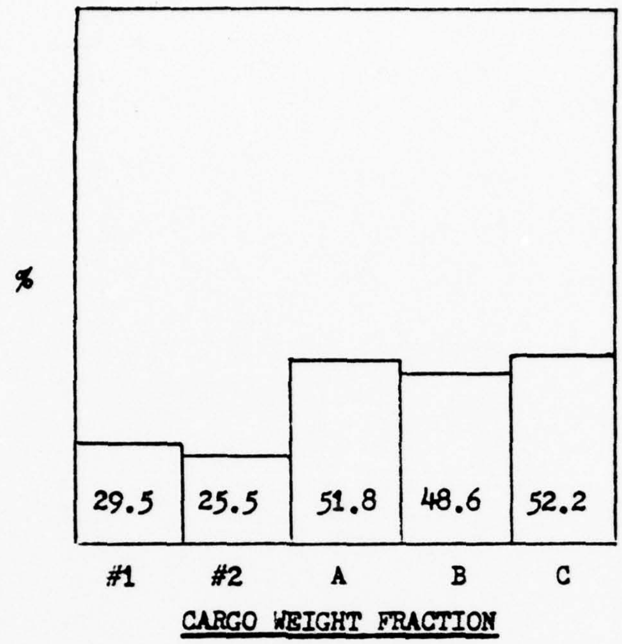
From a cost standpoint, military payload will obviously have a greater effect on the cost of the Naval vessels than on the cost of commercial vessels because of the equipment costs and the labor cost to install it.

In summary, the following statements can be made concerning the military payload functional category:

- The impact of military payload on the commercial vessels is negligible.
- The merchant vessels have a military payload only in the sense that they have a communications and radar navigation capability. These items are standard on U.S. ocean going vessels.
- The military payload does not account for a significant portion of the total difference between the Naval and commercial vessels.

3.3.7 Cargo Payload

There is a significant difference in cargo carrying ability between the Naval and commercial vessels. Figure 18 displays the cargo weight and volume fractions. The cargo weight fractions of the commercial vessels are about 75-80% greater than those of the Naval cargo



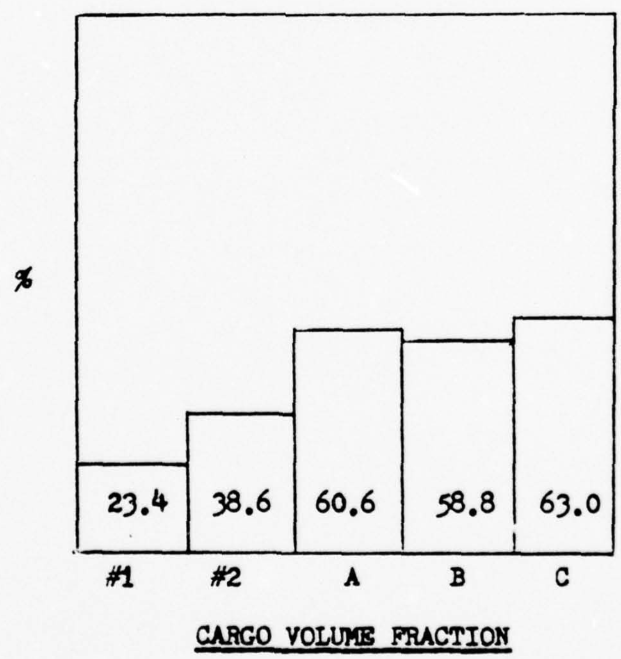


FIGURE 18 Cargo Weight And Volume Fractions - Cargo Vessels

vessels. For the same full load displacement, the commercial cargo vessels carry between 75% and 80% more cargo by weight than the Naval vessels.

The cargo volume fractions of the commercial cargo vessels are about 95% greater than those of the Naval vessels. The cargo volume fractions of the Naval vessels are relatively small because the total internal volumes of the Naval vessels are significantly greater than those of the commercial vessels. In terms of the amount of cargo volume a vessel has for a given full load displacement, the Naval vessels' are much more competitive. This can best be seen by normalizing the cargo volume by dividing by the full load displacement. The value that results is the cubic feet of cargo capacity per ton of displacement (at full load displacement).

Vessel	$V_{cargo}/\Delta (ft^3/ton)$
Navy #1	25.0
Navy #2	43.5
A	39.5
B	35.6
C	39.0

The cargo volume per displacement values of the Naval vessels bracket those of the commercial vessels. The difference in the values for the two Naval vessels can be explained by the type of cargo carried.

Naval vessel #1 carries various types of ammunition while Naval vessel #2 carries refrigerated stores, fleet freight, general stores, spare parts and dry provisions. The values for cargo volume per unit displacement of the commercial vessels are not substantially different. Vessels A and C carry general break-bulk cargo and liquid cargo. Vessel B carries refrigerated cargo in addition to the break-bulk and liquid cargo.

In designing a break-bulk cargo vessel to carry a particular type cargo there must be a matching of the weight and the volume required for the cargo. The Naval vessels carry 75%-80% less cargo by weight than the commercial vessels yet the amount of cargo volume per unit displacement is more in line with that of the commercial vessels. A partial explanation for this is the difference in types of cargo carried. The main reason for this however, is that a certain portion of the Naval vessel's cargo holds must be left vacant to allow the cargo to be accessible while at sea in order to facilitate underway replenishment operations. There is a greater amount of broken stowage in the cargo holds of the Naval vessels. More volume is needed for the cargo on the Naval vessels than would be warranted by the density of the cargo alone. This requirement impacts the total internal volume required.

In summary, the following observations can be made relative to the cargo payload carrying abilities of the Naval cargo replenishment and commercial cargo vessels:

- The Naval vessels carry considerably less cargo by weight than the commercial vessels.

•The difference in the relative amount of volume dedicated to cargo carrying by the Naval and commercial vessels is less than the difference in the relative amount of weight. The reason for the imbalance between weight and volume of cargo can be explained primarily by the greater amount of broken cargo stowage required on the Naval vessels to allow accessibility of the cargo at sea.

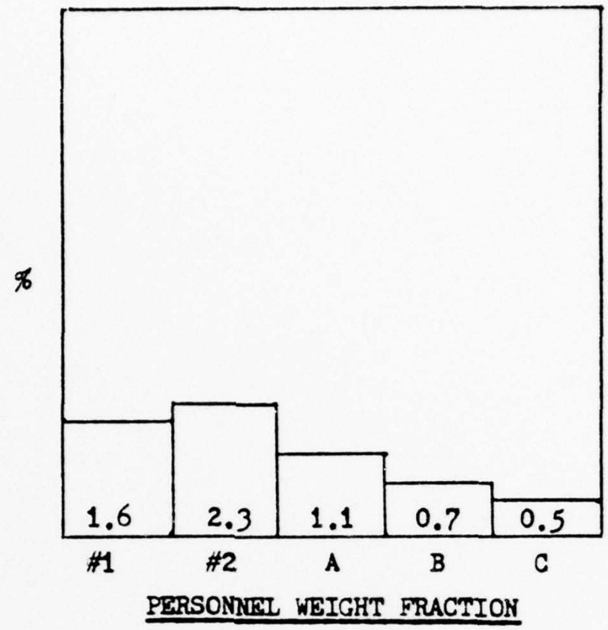
3.3.8 Personnel

There are significant differences between the Naval vessels and the commercial vessels in the personnel area. The differences include almost an order of magnitude larger crew size and significantly lower habitability standards for the Naval vessels. Figure 19 displays the personnel functional weights and volumes.

The weight impact of personnel on the Naval vessels is from two to four times larger than the impact on the commercial vessels, although the total impact on the full load displacement is very small. The personnel weight fraction can be explained as the product of two quantities:

- personnel specific weight
- personnel capacity/ship size ratio

Table 21 shows the personnel weight fractions expressed as the product of these two parameters. As can be seen in this table, the personnel specific weights of the Naval vessels are from one fourth to one third the value of those on the commercial vessels. The personnel specific



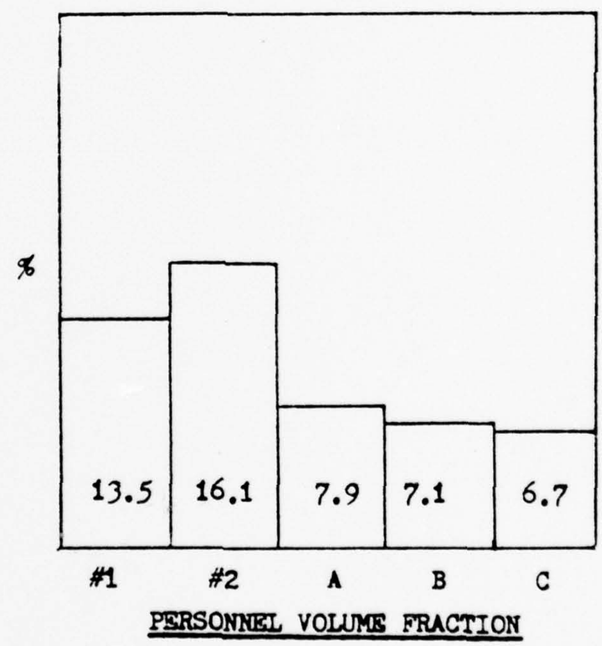


FIGURE 19 Personnel Weight And Volume Fractions - Cargo Vessels

TABLE 21

CARGO VESSELS' PERSONNEL WEIGHT FRACTION EXPRESSED AS THE PRODUCT OF THE PERSONNEL SPECIFIC WEIGHT AND THE PERSONNEL CAPACITY/SHIP SIZE RATIO

Vessel	Personnel Weight Fraction x 100 (%)	=	Personnel Specific Weight (tons/man)	x	Personnel Capacity/Size Ratio (men/100 tons)	x	Conversion Factor (1/100)
Navy #1	1.64		0.85		1.92		1/100
Navy #2	2.32		0.84		2.77		1/100
A	1.11		3.61		0.31		1/100
B	0.74		2.75		0.27		1/100
C	0.52		2.67		0.19		1/100

weights of the Naval vessels are less for two reasons. First, the habitability standards are much lower on the Naval vessels and second, there is an economy of size effect. In order to show these effects, it is necessary to divide the personnel weights into the following three categories:

- living weight
- personnel support weight
- personnel stowage weight

	Units	Navy #1	Navy #2	A	B	C
Living Specific Weight	tons/man	0.23	0.29	0.54	0.66	0.64
Personnel Support Specific Weight	tons/man	0.09	0.05	0.12	0.25	0.16
Personnel Stowage Specific Weight	tons/man	0.53	0.49	2.95	1.84	1.87

Living specific weight is comprised of furnishings for living spaces and the load item, crew and effects. The amount of furnishings alloted for each Navy crew member is considerably less than that of a merchant crew member.

The personnel support specific weight is made up primarily of galley, pantry, scullery and commissary outfittings. The magnitude of the support specific weight shown above is indicative of an economy of size effect and points out that the only real difference is that with the larger crew size, the Naval vessels are forced to have a greater amount of personnel support equipment.

The personnel stowage specific weight is made up of potable water, provisions and stores. The relative magnitudes of the personnel stowage specific weights reflect the greater amount of fresh water alloted to each crew member on the commercial vessels and the larger amount of provisions and stores carried for each crew member.

As can be seen in table 21, the personnel capacity/ship size ratios of the Naval vessel are an order of magnitude larger than those of the commercial vessels. Crew size was broken down into five categories as follows.

	Navy #1	Navy #2	A	B	C
Deck	164	185	12	13	10
Engineering	104	100	10	12	6
Steward	69	131	9	9	5
Officers	17	26	14	14	12
Other	3	4	8	8	8
Total	357	446	53	56	41

The deck complement for the Naval vessels is greater because of the military requirements, such as weapons, electronics, communications and evaluation, and because of the continuous underway replenishment capability which implies in part that the ship's force be able to rig all transfer-at-sea stations simultaneously.

There is a considerable difference in the engineering department crew sizes between these Naval and commercial vessels. The engineering department on the Naval vessels includes not only the engine room and fireroom personnel but also, includes the following ratings: machinery repairs, damage control, internal communications, electricians and enginemen.

Supply crew size differences can be explained primarily by the fact that the larger crew size of the Naval vessels requires more support and administrative personnel and the nature of the ship's primary mission of underway replenishment requires a large number of storekeepers and clerks to insure that supply system orders are filled in a rapid fashion.

In summary, the personnel weight fractions of the Naval vessels are larger than those of the commercial vessels because of the larger crew size. The Navy's lower habitability standards reduce the impact of personnel weight on full load displacement. The use of commercial habitability standards on Naval vessels without a large reduction in crew size would have a drastic impact on ship size.

The volume impact of personnel is far greater than the weight impact. The personnel volume fractions of the Naval vessels are about twice as large as that of the commercial vessels. The personnel specific volumes of the commercial vessels are about three times those of the Naval vessels.

	Navy #1	Navy #2	A	B	C
Personnel Specific Volume (ft^3/man)	728	654	1670	1619	2430

The majority of this difference is the result of the amount of living space devoted to each man. In order to see this, the personnel specific volumes must be broken down into the following three categories:

- Living specific volumes
- Personnel support specific volumes
- Personnel stowage specific volumes

		Navy #1	Navy #2	A	B	C
Living Specific Volume	ft^3/man	379	333	1120	1154	1471
Personnel Support Specific Volume	ft^3/man	202	150	312	232	225
Personnel Stowage Specific Volume	ft^3/man	145	169	239	233	186

The living volume category is comprised of berthing, sanitary and messing spaces. The majority of the difference in personnel volume between Naval and commercial vessels can be attributed to this subgroup. The habitability standards for the living spaces on these commercial vessels call for two man staterooms with a toilet and shower being shared by four men. The amount of space alloted to each man for these

functions is far less on these particular Naval vessels. The personnel support and stowage specific volumes are slightly greater on the commercial vessels, however, these differences are of secondary importance.

From a cost standpoint, the personnel functional group has a greater impact on the Naval vessels. This is due to the larger crew size. The cost of the furnishings and the commissary equipment on the Naval vessels would be significantly greater.

In summary, the following statements can be made concerning the impact of personnel on the Naval and commercial vessels.

- The weight and volume impact of personnel is much greater on the Naval vessels. Of the two, the volume impact predominates.
- Personnel volume requirements have a significant impact on the amount of enclosed volume that is required for the Naval vessels.
- Personnel volume requirements are greater on the Naval vessels becuase of the order of magnitude larger crew size.
- The habitability standards of the Naval vessels are considerably less than those of the commercial vessels. In terms of the volume per man dedicated to berthing, sanitary and messing facilities, the commercial vessels allot four times as much as the Naval vessels.

•The lower habitability standards of the Naval vessels reduce the impact of personnel weight and volume on ship size relative to what it would be if commercial habitability standards were used on the Naval vessels.

3.3.9 Liquids

With the exception of the cargo and the structural weight fractions, the liquids weight fraction has a greater impact on full load displacement than any of the other functional categories. The liquids volume fraction, however, has considerably less impact on total ship volume. The reason for this is that relative to the other functional groups, the density of liquids is much greater and hence the weight impact would be greater than the volume impact.

Figure 20 displays the liquids weight and volume fraction. As can be seen, the weight impact of liquids is about 15% greater on the Naval vessels. The volume impact is greater on the commercial vessels. This is so because the total internal volume of the Naval vessels are much greater than those of the commercial vessels and thus the volume impact of liquids would be considerably less.

In order to determine why the liquids weight fraction is greater on the Naval vessels it is necessary to subdivide the liquid weights into its component parts.

- endurance fuel oil
- reserve feed and demineralized water

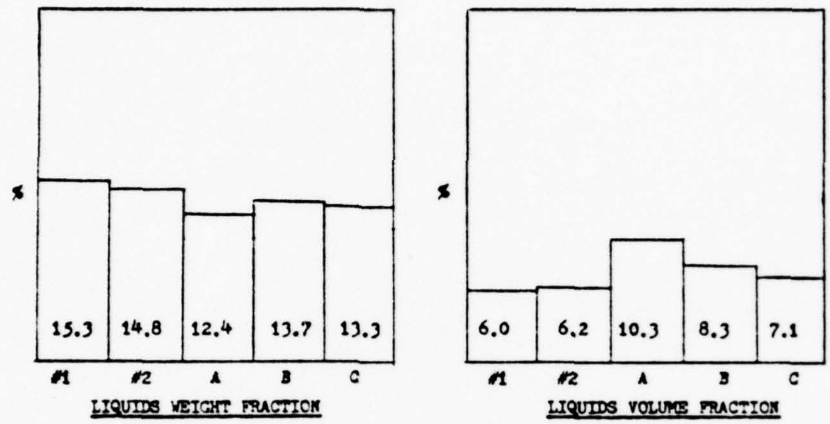


FIGURE 20 Liquids Weight And Volume Fractions - Cargo Vessels

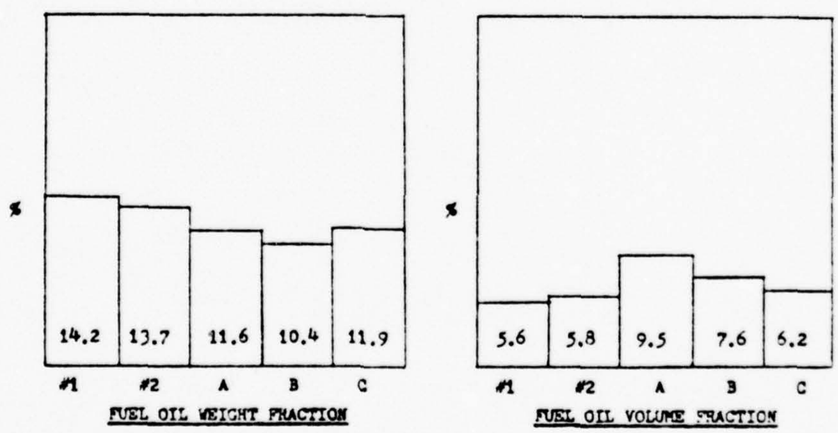


FIGURE 21 Fuel Oil Weight And Volume Fractions - Cargo Vessels

•lube oil

•miscellaneous liquids

•piping tunnels

As can be seen from figure 21, the endurance fuel oil accounts for the vast majority of the liquids weight and the relative magnitudes of the fuel oil weight fractions are about the same as those of liquids category as a whole. Endurance fuel oil accounts for the greater liquids weight fraction of the Naval vessels. There are no significant differences between the Naval and commercial vessels in the weight fractions associated with the other liquids subgroups. It is interesting to note that the Naval vessels carry a greater amount of endurance fuel oil and yet their endurance range is substantially less.

Vessel	Endurance Fuel Oil (tons)	Endurance (n.m.)	V_e (knots)
Navy #1	2641	10,000	20
Navy #2	2209	10,000	18.5
A	2000	14,400	18.0
B	2200	10,870	20.0
C	2503	13,410	20.0

There are several reasons for this effect. First, the electrical cruising load of the Naval vessels are from two to four times greater than those of the commercial vessels. Second, the hull form of the Naval vessels is less efficient from a hydrodynamic standpoint as was discussed in section 3.2.

In summary, the following statements can be made concerning the relative impact of liquids on the Naval and commercial vessels:

- The weight impact of liquids on full load displacement for all the vessels is relatively large.
- The liquids functional weight fraction is larger for the Naval vessels because of the relatively large amount of fuel oil that must be carried.
- The Naval vessels carry more fuel oil than the commercial vessels in spite of having less cruising range because of the relatively poor hydrodynamic characteristics of the Naval hulls and because of the greater electrical loads of the Naval vessels.

Section 3.4 Summary and Conclusions

In the comparison of Naval cargo replenishment and commercial cargo vessels, several observations and conclusions can be stated:

- From a commercial point of view, the Naval vessels are poor performers relative to the merchant cargo vessels. The Navy ships require more horsepower to travel at the same speed as the commercial vessels. They carry far less cargo by weight and volume than the commercial vessels, and they have significantly less range in spite of carrying more endurance fuel oil. In addition, the Navy ships are more expensive to build and to operate.

•The Naval vessels exhibit such poor performance from a commercial point of view primarily because of the underway replenishment capability.

•The primary differences in most of the functional categories between the Naval cargo replenishment ships and the commercial cargo vessels can be traced directly or indirectly to the performance requirements or support equipment needed for the underway replenishment capability. The largest impact of this capability is in the amount of internal volume that is required. The large amount of internal volume results in greater structural weight due to the greater number of decks in the Naval vessels. The underway replenishment capability is directly responsible for the large electrical capacity, the greater number of auxiliary subsystems and the more extensive other ship operations functional group. In addition, the underway replenishment capability requires a large number of personnel. Indirectly, the large amount of equipment which supports the underway replenishment capability and is located within the machinery box cause the volume impact of main propulsion to be greater on the Naval vessels.

- Differences in design criteria or practices have less of an effect on the total difference between Naval and commercial vessels than does the greater performance or support required in each functional category to permit underway replenishment operations. Differences in the design criteria or practices have the largest impact in the structural and main propulsion areas where the Naval practices saved weight but may have had offsetting effects such as increased construction and maintenance costs.
- Differences between the Naval and commercial vessels caused by the larger military payload of the Naval vessels are of secondary importance.
- The greater damage control capabilities of the Naval vessels reflect the fact that Naval auxiliary type ships may have to carry out their mission in a limited combat environment. This explains the greater fire fighting and damage repairing capability, and the more stringent stability and buoyancy after damage requirements. While considered an important part of the Naval vessel design, these capabilities do not account for a major portion of the difference between Naval and commercial vessels in each functional area.

CHAPTER 4

A COMPARATIVE ANALYSIS OF NAVAL OILERS AND COMMERCIAL TANKERS

The purpose of this chapter is to identify and quantify the design differences between Naval oilers and commercial tankers. Wherever possible, the dollar cost impact of the design differences will be discussed. In general, design differences result from performance requirement differences and from the different design criteria or practices used by Naval and commercial designers. The analysis is conducted by comparing the gross characteristics and the overall vehicle performance indices of each of the vessels. A comparison of the Naval and commercial vessels is then made in each of the functional categories as discussed in Chapter 2.

The identities of the vessels had to be disguised because of the proprietary nature of the vessel characteristics and capabilities and because of the sensitive nature of certain information concerning the Naval vessels. The Naval oilers are referred to as Navy #3 and Navy #4 while the commercial tankers are designated D, E and F. Navy #3 is a fleet oiler while Navy #4 is a replenishment oiler. The difference is in terms of the types of cargo carried. Tankers D and E are grade B liquid product carriers and are subsidized by the Maritime Administration. Tanker F is a grade B liquid product carrier which is chartered by the Military Sealift Command from a private shipping company.

The gross characteristics of each of the vessels are discussed in Section 4.1 and the overall performance indices are compared in Section 4.2. Each functional category is analyzed individually in Section 4.3 An overall summary and the conclusions of the analysis are provided in Section 4.4.

Section 4.1 Gross Characteristics

Gross characteristics provide an overall description of the physical characteristics and operational capabilities of a vessel. Identification of gross characteristic differences among vessels serves as the starting point of any comparative analysis.

Table 22 lists the gross characteristics for each of the vessels. There are a number of important observations that can be made:

- There is a wide variance in the values of the full load displacement between the Navy oilers and the commercial tankers. This reflects the fact that as liquid cargo carriers, the Naval tankers are very small by today's commercial standards. Even these commercial tankers are small when compared to the mammoth tankers which are being built today. These particular commercial tankers were selected for use in this analysis because of all the commercial tankers built recently and for which information could be obtained, they are closest in size to the Navy oilers.
- For a given displacement, the Navy oilers have a significantly greater amount of internal volume.
- There is a significant difference in hull form. The Naval vessels have wider beams, longer lengths for a given displacement, greater depth and slightly less draft than the commercial tankers. The prismatic and block coefficients of the Naval vessels are considerably less.

TABLE 22

NAVY OILERS AND COMMERCIAL TANKERS - GROSS CHARACTERISTICS

	Navy #3	Navy #4	D	E	F
Size					
Δ, Full load (tons)	26,205	37,630	47,281	44,150	33,990
∇_T, (ft^3)	1,949,000	2,881,000	2,477,000	2,357,000	1,900,000
Length Between Perpendiculars (ft)	550	638.7	660.0	684.6	560.3
Beam (ft)	88	96	90	84	84
Draft (ft)	31.3	33.3	35.0	34.5	34.6
Depth (ft)	48	56.0	47	45.5	45.5
Prismatic Coefficient (C_p)	0.618	0.658	0.801	0.787	--
Block Coefficient (C_b)	0.605	0.645	0.793	0.778	0.732
Main Engines	Geared Turbine (1)	Geared Turbines (2)	Geared Turbine (1)	Medium Speed Diesel (Reversing)	Medium Speed Diesel (Non-Reversing)
SHP					
Commercial Rating Max Continuous	--	--	15,000	14,000	14,000
Naval Rating Cruising	18,400	28,000	--	--	--
Full Power	24,000	32,000	--	--	--
Endurance/Sustained Sea Speed (knots)	20.0 @18,400 SHP	20.0 @28,000 SHP	16.0 @12,000 SHP	15.75 @11,200 SHP	16.0 @11,200 SHP

TABLE 22 (cont.)

	Navy #3	Navy #4	D	E	F
Speed at Full Power (knots)	20+	20+	--	--	--
Endurance @ Sustained Sea/ Cruising Speed	6000	6500	12,000	12,000	12,000
Electric Plant	3 SSTG's 7500 KW 1 emer. diesel gen. 750 KW	4 SSTG's 8000 KW 1 emer. diesel gen. 500 KW	1 SSTG 1000 KW 1 aux. diesel 750 KW 1 emer. diesel gen. 200 KW	2 Diesel Gen 1200 KW 1 emer. diesel gen. 100 KW	2 Diesel Gen 2000 KW 1 gen. attached to main gear box 600 KW 1 emer. diesel gen. 150 KW
Complement	183	432	31	27	32
Weight of Cargo Carried (tons)	15,711	21,585	36,000	31,600	23,700
Volume of Cargo Spaces (ft^3)	777,000	1,277,000	1,637,000	1,766,000	1,294,000
Type Cargo Carried	Cargo Fuel Oil, JP-5 Cargo Stores	Cargo Fuel Oil, JP-5 Cargo Bulk, Mail, Lube Oil, Refrigerated Cargo, Cargo Ammunition	Grade B Liquids	Grade B Liquids	Grade B Liquids

- The Navy oilers have almost twice the installed horsepower of the commercial vessels and a significantly greater endurance speed.
- The cruising radii of the Naval vessels are about one-half those of the commercial tankers.
- The installed electrical capacities of the Naval vessels are about four times as great as those of the commercial tankers.
- There is a significant difference in crew size.
- For a given displacement the commercial tankers carry 25% more cargo by weight than the Naval vessels.
- In addition to petroleum based cargo, the Naval tankers carry dry cargo.
- As is visible in Table 23, the underway replenishment capabilities of the Naval vessels are quite extensive while those of the commercial tankers are either minimal or non-existent.

Many differences between the Naval oilers and commercial tankers have been identified. Among those identified are: size and shape differences, installed capacity differences such as shaft horsepower and electrical power and differences in cargo carrying ability. The impact of these differences on the design of the individual vessels will be revealed in the functional category analysis discussed in Section 4.3.

TABLE 23

NAVY OILERS AND COMMERCIAL TANKERS -- UNDERWAY REPLENISHMENT CAPABILITIES

Navy #3

- Fueling at Sea (FAS) Sending and Receiving Stations (Alongside Method)
  - 3 port
  - 3 stbd
- Replenishment at Sea (RAS) Sending and Receiving Stations (Alongside Method)
  - 1 port
  - 1 stbd
- Helicopter Facilities
  - landing facilities for H-1, H-2, H-3, H-46, H-53

Navy #4

- FAS Sending and Receiving Stations (Alongside Method)
  - 4 port
  - 3 stbd
  - 1 stbd (receive only)
- RAS Sending and Receiving Stations (Alongside Method)
  - 2 port
  - 2 stbd
- Helicopter Facilities
  - landing facilities for H-1, H-2, H-3, H-46

Tanker D

- FAS Sending only (Astern Method) - fuel discharged at reduced rates

Tanker E

- No capability

Tanker F

- Can deliver bulk petroleum products to a fleet oiler at sea while underway and steaming alongside. Fleet oiler will supply and pass over span wires and cargo hoses for use on one side of ship at a time. Stations equipped for service using single probe system or conventional hose system.

Section 4.2 Overall Vehicle Performance Indices

An overall performance indice measures the cost associated with a particular performance feature. The cost may be expressed in dollars directly or indirectly in terms of a functional capacity which must be incorporated into the vessel design. In general, the greater the functional capacity, the greater the dollar cost of that functional category and the lower the value of the performance indice. In this analysis three overall vehicle performance indices were used:

- Transport efficiency $\Delta V_e/SHP$
- Speed productivity index $W_c V/\Delta$ (knots)
- Distance productivity index $W_c R/\Delta$ (miles)

The values of these parameters for each of the vessels are listed in Table 24.

The transport efficiency is a measure of the hydrodynamic performance of the vessel. The performance being measured is the amount of power that is required to propel a vessel of a given displacement at a certain speed. The higher the value of this indice, the greater the transport efficiency. As can be seen in Table 24, the transport efficiencies of the commercial tankers at endurance speeds are much greater.

The larger values of the commercial tankers reflect the economic factors of transporting liquid products. The minimum cost per ton mile is achieved by carrying as great an amount of oil as possible at moderate speeds. The low values of the transport efficiency for the Navy oilers are the result of the 20 knot cruising speed requirement. The greater

TABLE 24

OVERALL VEHICLE PERFORMANCE INDICES -- TANKERS

Vessel	$\frac{\Delta V_e}{SHP}$	$\frac{W_c V}{\Delta}$	$\frac{W_c R}{\Delta}$
Navy #3	28.5	12.0	3600
Navy #4	26.9	11.6	3770
D	63.0	12.2	9120
E	62.1	11.3	8640
F	48.6	11.2	8400

cruising speed requirement impacts not only the size of the propulsion plant that is required but also requires a much finer hull form. This feature has an adverse effect on the hull construction costs of the Navy oilers.

The speed productivity index indicates the speed with which a certain amount of cargo can be transported for a given size vessel as measured by the full load displacement. As can be seen in Table 24, the value of this performance indice for each of the vessels is about the same. In general, this index measures both the amount of cargo that can be transported for a given size vessel and the speed with which the vessel can travel. The cruising speeds of the Navy oilers are about 25% greater than those of the commercial tankers but the cargo capacity is 25% less. This difference merely reflects what is considered important by the naval and commercial designers. The commercial designer wants to design a vessel with the maximum earning capacity. He does this by maximizing the cargo payload and transporting it at a moderate speed. For the naval designer speed is important for military reasons. The lower cargo payload is due in part to the greater speed requirement but mainly to the underway replenishment capability which has a weight and volume impact on each functional category.

The distance productivity index reveals the range a certain amount of cargo can be transported by a given size vessel as measured by full load displacement. In general, a low value of this parameter can be the result of a lower endurance, less cargo carrying ability or a

combination of the two. As can be seen in Table 24, the Navy oilers have relatively low marks. The distance productivity indexes of the Navy oilers are about 60% of those of the commercial tankers. These low values are the result of less cargo carrying ability and less range. The greater range of the commercial tankers is primarily the result of carrying more endurance fuel oil but is also due to the more economical endurance speed and the lower electrical cruising load. This is revealed by comparing the ton-miles per 1000 tons of fuel oil for each of the vessels.

Vessels	Ton-miles/1000 tons of fuel oil
Navy #3	98.0
Navy #4	93.1
D	186.1
E	178.2
F	137.1

The electrical cruising loads of the Navy tankers are from two to three times as large as those of the commercial tankers.

Section 4.3 Functional Comparison

The total weight and volume for each of the vessels was subdivided and assigned to one of the functional groups as discussed in Chapter 2. The functional weights and volumes that were calculated for each of the vessels are listed for reference in Appendix B. The analysis of each

functional category will be presented individually beginning with those groups which comprise the basic vehicle and followed by those which make up the useful load group. Each of the vessels will be analyzed at increasing levels of detail until the reasons behind the major differences in their design indices are identified.

Figures 22 and 23 are graphic representations of the weight and volume allocations that were computed for each of the five vessels. The number within each box refers to either the weight or volume fraction. The weight fraction is the weight devoted to that functional group divided by the full load displacement. The volume fraction is the volume associated with that particular group divided by the full load displacement. The height of the entire bar graph indicates the relative magnitudes of the full load displacement and the total internal volume for each of the vessels.

As can be seen in Figure 22 there are significant differences in the weight allocations between the Naval and commercial vessels. The structural weight fractions of the Navy oilers are about 50% greater than those of the commercial tankers. The main propulsion, auxiliary and other ship operations weight fractions of the Naval vessels are from two to three times larger than those of the commercial tankers. The cargo carrying capacities of the Naval vessels are about 20% less than those of the commercial tankers. The electrical, military, and personnel weight fractions of the Naval vessels are larger but their impact on full load displacement is small.

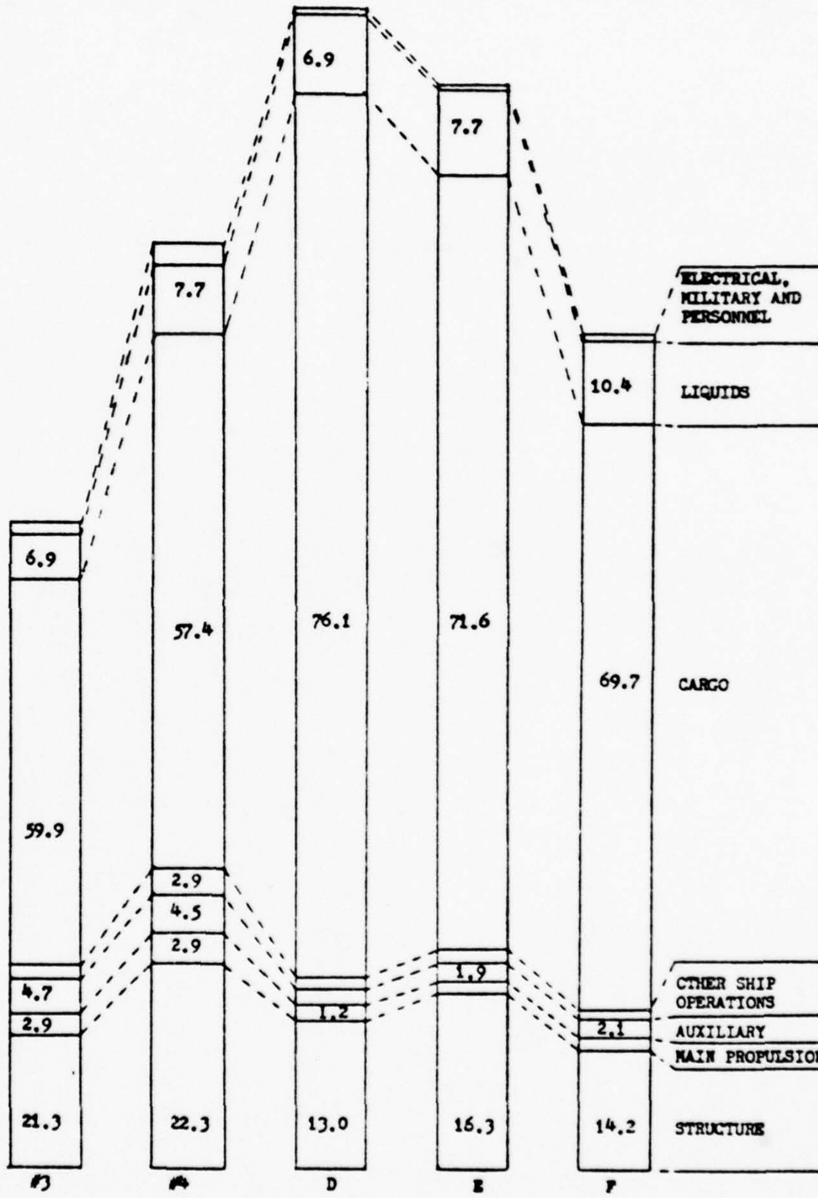


FIGURE 22 Comparison of Weight Allocations - Tankers

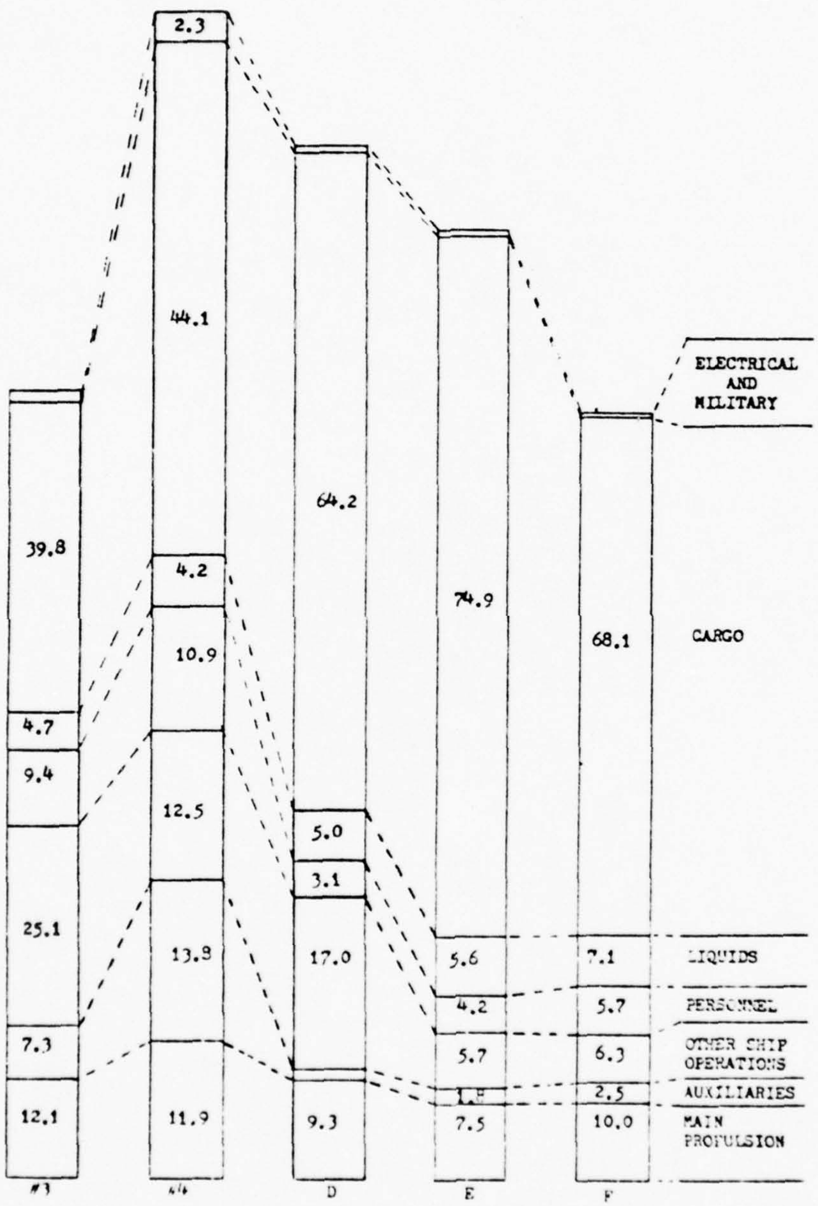


FIGURE 23 Comparison of Volume Allocations - Tankers

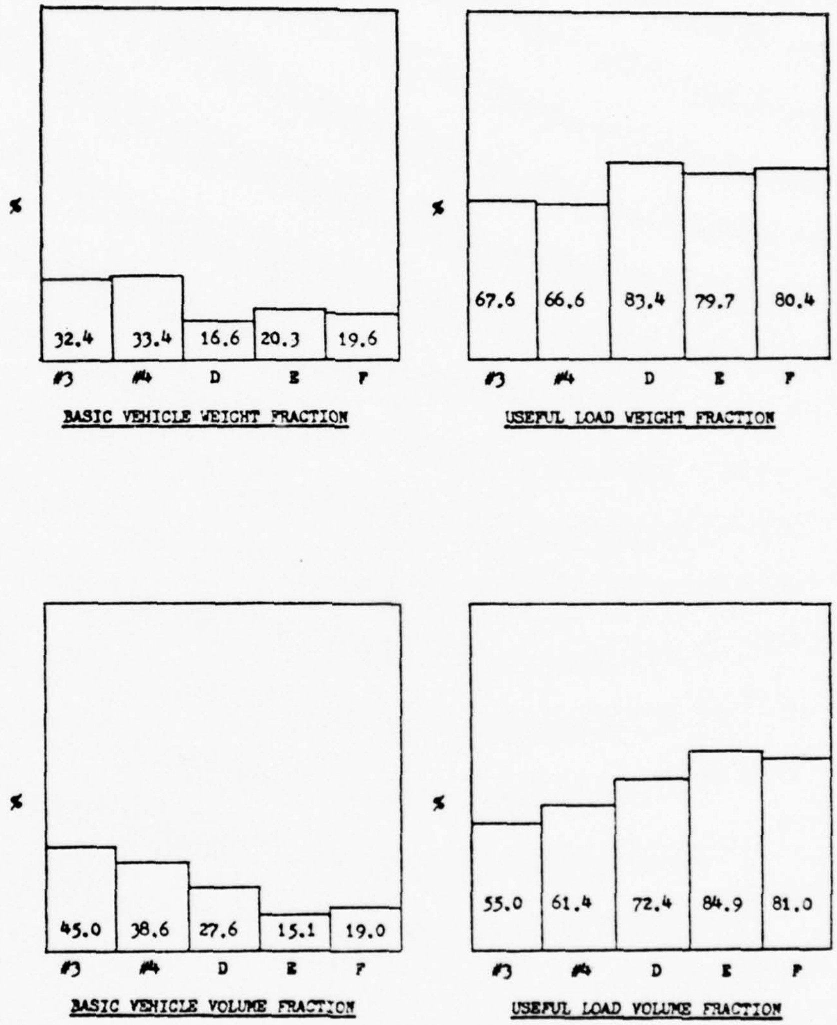


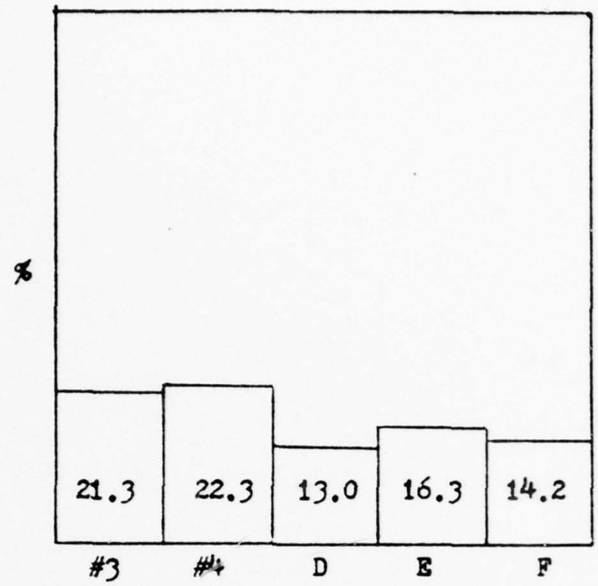
FIGURE 24 Basic Vehicle and Useful Load Weight and Volume Fractions - Tankers

Figure 23 reveals that there are significant differences in the auxiliary, other ship operations and personnel volume fractions. The main propulsion volume fractions of the Navy oilers are about 20% greater than those of the commercial tankers. The cargo volume fractions of the commercial tankers are significantly greater. The electrical and military volume fractions are larger for the Naval vessels but their total impact on total volume is small.

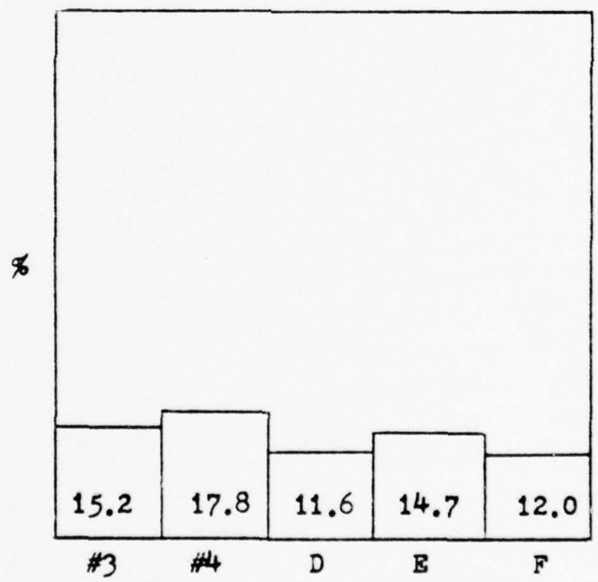
Figure 24 displays a graphical comparison of the basic vehicle and useful load weight and volume fractions for each of the vessels. As can be seen, the basic vehicle weight and volume fractions of the Naval vessels are considerably greater than those of the commercial tankers. As a result, the amount of weight and volume that can be devoted to useful load is less. In the functional analysis that follows, the reasons for the larger basic weight and volume fractions and the corresponding lower useful load weight and volume fractions will be identified.

4.3.1 Structure

There is a significant difference in the impact of structure on the Navy oilers and the commercial tankers. Figure 25 is a graphical representation of the structural weight fractions for each of the vessels. As can be seen, the structural weight fractions of the Navy oilers are about 50% greater than those of the commercial tankers. Unnecessary structural weight is very expensive in terms of acquisition cost and from a loss of payload carrying ability. As opposed to the Navy's combatant



STRUCTURAL WEIGHT FRACTION



HULL GIRDER WEIGHT FRACTION

FIGURE 25 Structural Weight Fractions - Tankers

ships, Naval auxiliary type vessels are not designed to resist weapons effects and are not required to have the capability of sustained service in all sea conditions. However, non combatant auxiliary ships provide support for combatant vessel and can be expected to operate in limited combat environments. It has been the Navy's policy that "selected standard merchant ship design and construction practices may be used for auxiliary vessels."[12] The Navy's structural design approach has largely been based on the contention that "weight costs money."[11] This policy and this philosophy have caused the Naval auxiliary structural designer to approach the design in a certain fashion. In light of these statements concerning the Navy's structural design philosophy it is necessary to determine why the structural weight fractions of the Navy oilers are so much larger than those of the commercial tankers.

In order to begin the structural analysis it is helpful to subdivide the structural weight into the following eight categories:

- foundations
- structural bulkheads
- doors, hatches
- masts and kingposts
- superstructure
- decks, platforms and flats
- hull framing, plating and inner bottom plating
- remainder

Figure 26 is a graphical representation of the percentage of full load displacement occupied by each of these subgroups. In order to analyze the differences between the Naval and commercial vessels it is necessary to examine the portions of the structure which are the primary load carrying members. Figure 27 is a graphical presentation of the three structural weight groups which make up the hull girder, the primary load carrying structure. This figure has the same relative shape as Figure 26, so the deletion of the other five structural groups reveals the fact that a significant portion of the differences in structural weight fraction between the Naval and commercial vessels can be explained by the weights of the hull girder. Figures 25 and 27 shows that the hull girder weight fractions of the Naval vessels are from 3% to 50% greater than those of the commercial tankers.

The hull girder weight fractions can be expressed as the product of the hull girder specific weight ratio and the hull girder size indicator. Table 25 displays the mathematics of this relationship. It must be pointed out that these two terms are not independent of each other. There is a certain amount of coupling between the terms. However this concept, when used with care, enables the designer to assess the impact of differences in design standards and practices and the impact of differences in hull configuration on the hull girder weight fraction. The hull girder specific weight ratio is affected by differences in design standards or practices, hull configuration and materials. The hull girder size indicator gives insight to the effect of differences in hull configuration on the hull girder weight fractions.

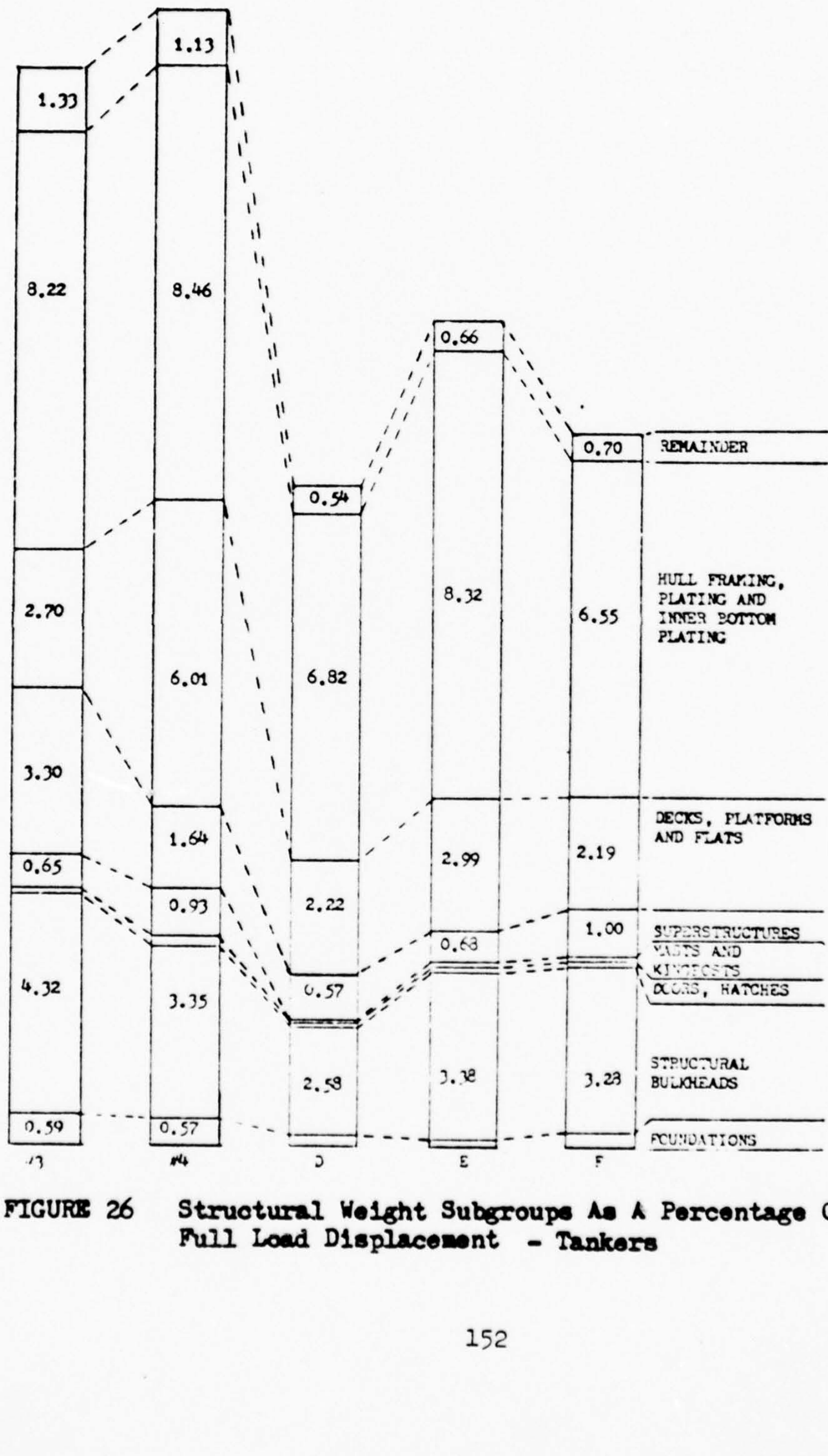


FIGURE 26 Structural Weight Subgroups As A Percentage Of Full Load Displacement - Tankers

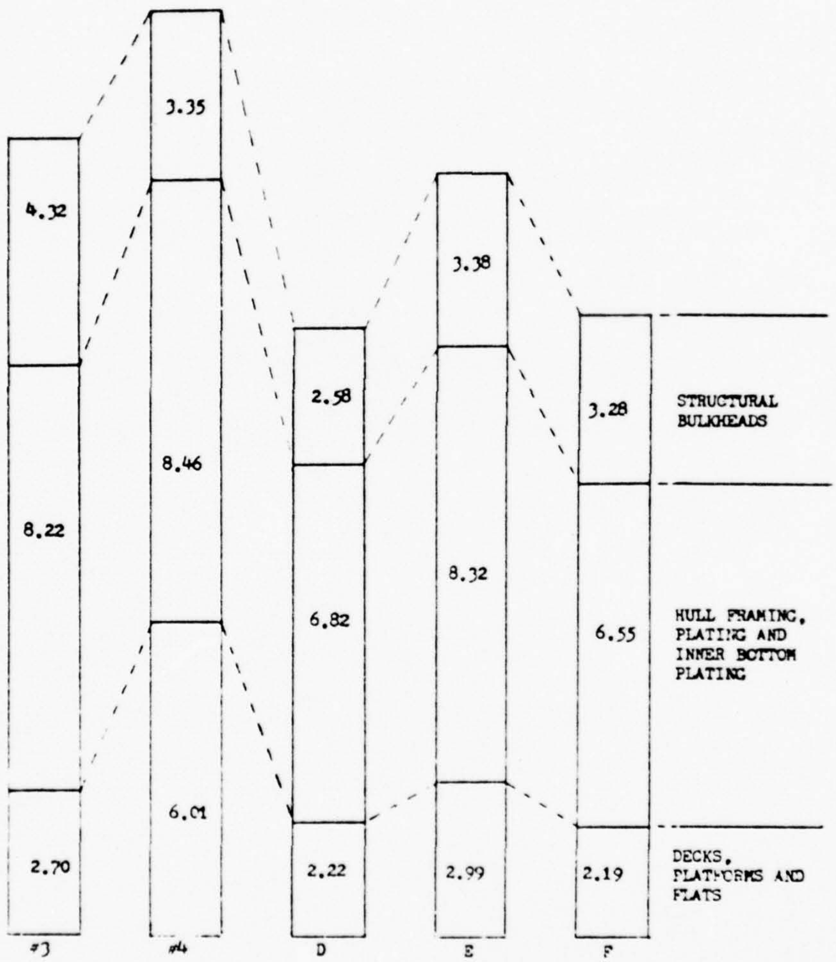


FIGURE 27 Structural Weight Of Hull Girder Elements As A Percentage Of Full Load Displacement

TABLE 25

TANKER HULL GIRDER WEIGHT FRACTIONS EXPRESSED AS THE PRODUCT OF THE HULL GIRDER SPECIFIC WEIGHT RATIO AND THE HULL GIRDER SIZE INDICATOR

Vessel	Hull Girder Weight Fraction x 100 (%)	=	Hull Girder Specific Weight Ratio (lbs/ft^3)	x	Hull Girder Size Indicator (ft^3/ton)	x	Conversion Factor (1 ton/2240 lbs)
Navy #3	15.2		5.67		60.2		1/2240
Navy #4	17.8		6.01		66.7		1/2240
D	11.6		5.32		48.9		1/2240
E	14.7		6.69		49.2		1/2240
F	12.0		5.35		50.4		1/2240

There are two observations that can be made with respect to Table 25. First, the magnitudes of the hull girder specific weight ratios vary from vessel to vessel. This is a change from that which was observed with the cargo vessels where the specific weight ratios of the Naval vessels were less than those of the commercial vessels. Second, the hull girder size indicators of the Navy oilers are 25% greater than those of the commercial tankers. The impact of each of these terms on the hull girder weight fraction will be discussed.

The hull girder size indicators of the Navy oilers are greater than those of the commercial tankers because of the differences in hull configurations. There are two primary differences between the Navy and commercial hulls. First, the Navy oilers have a longer length for a given displacement which is primarily the result of the greater speed requirement. Second, the depths of the Naval hull are greater than those of the commercial hulls. The Naval hulls have slightly shallower drafts and significantly greater freeboards than the commercial tankers.

The freeboards of the Naval tankers are greater than those of their commercial counterparts for several reasons:

- There are functions other than cargo cubic which are required within the hull of Naval tankers that are not needed in commercial hulls. For example, dry cargo stowage and cargo handling areas. This effect applies primarily to oiler #4.
- Larger freeboards permit refueling operations in higher sea states.

•In the design of commercial tankers of this size, once the draft is set there is a tendency to minimize the hull depth by minimizing freeboard. Requirements for stability and buoyancy after damage restrict the amount that freeboard can be reduced. Excessive freeboard in these commercial tankers results in wasted cargo cubic.

The hull girder size indicator does not of itself explain why the structural weights of the Naval vessels are larger than those of the commercial tankers but it does reveal that the greater amount of volume that is required within the Naval hulls may have an adverse effect on the structural weight. As will be seen, the effect of required volume is much greater on oiler #4 than on oiler #3. The primary reason for this is that oiler #4 needs not just more volume within the hull, but considerably more deck space. This deck space will have an adverse effect on the hull structural specific weight and the hull girder weight fraction.

The greater depth combined with the longer length for a given displacement of oiler #3 results in more internal volume. It is the length that has an adverse effect on the structural weight of this vessel.

There are three factors which can effect the hull girder specific weight ratios.

•The differences in the criteria and practices governing the structural design of the Naval and commercial tankers.

•Difference in the material used.

•Differences in hull configuration.

The structural designs of the commercial tankers and the Navy oilers are governed by different standards. Commercial practice is governed by the American Bureau of Shipping's "Rules for Building and Classing Steel Vessels"[7] while Navy standards are covered in General Specifications for Ships of the United States Navy and the various structural design data sheets.[8][9] While the underlying principles are the same there are some differences between the two systems.

For vessels of the size and hull shape similar to those used in this study, the design of the midship section has a major impact on hull structural weight. In order to explain, at least partially, why the hull girder specific weight ratios of the commercial tankers are not greater than those of the Navy oilers as was the case with the commercial and Navy cargo vessels, it is necessary to examine certain changes in the ABS Rules that have taken place since the cargo vessels were built and then to compare the current ABS midship design procedures of the Navy and ABS.

Prior to 1966 when the commercial cargo vessels used in this analysis were built, longitudinal strength was not addressed directly by ABS Rules. Starting in 1966, ABS Rules began to specify standards of longitudinal strength by requiring a minimum hull girder section modulus. The Rules allowed effective longitudinal framing members to be included in the calculation of the section modulus. This allowed structural designers to take advantage of the more favorable orientation of longitudinally stiffened plate resulting in a lower structural weight for the same strength. Since the cargo vessels were designed prior to 1966, ABS Rules

did not allow reductions in plate thickness when the vessels were framed longitudinally. There was no advantage in terms of a structural weight savings to offset the lost cargo cubic that resulted in using longitudinal framing for the sides of the hull girder in commercial cargo vessels. The Naval cargo vessels used longitudinal framing for the entire hull girder and thus enjoyed a weight advantage relative to the commercial cargo vessels.

Since all the tankers were designed and built since 1966, the commercial tankers could take advantage of the longitudinal system of framing the hull girder and it did not impact the cargo cubic due to the nature of the cargo. Hence the Navy oilers lost a relative advantage over commercial tankers in structural weight that the Navy cargo vessels enjoyed with respect to the commercial cargo vessels. The gap that existed in structural specific weights would narrow.

From 1966 to 1974, ABS Rules specified the required section modulus in terms of the type of vessel, its length, beam and block coefficient. Starting in 1975, ABS specified the required section modulus by quantifying a nominal maximum total longitudinal bending moment and a nominal permissible longitudinal bending stress. The longitudinal bending moment is composed of a still water bending moment and a wave induced bending moment. The nominal permissible longitudinal bending stress is a function of vessel length. This change is significant in that ABS Rules now specifies the section modulus in terms of a longitudinal bending moment and an allowable primary stress which has been the practice of the Navy in structural design for some time. While the section modulus required by ABS Rules for vessels of

lengths similar to those used in this comparison (i.e., 650') has not changed significantly from 1966 to 1977 in spite of the change in the way it is to be calculated, specifying it in terms of a bending moment and an allowable stress level is a more rational approach to the longitudinal strength problem.

The Navy's approach in the early stages of design is to calculate the required modulus based on a bending moment and a design primary stress. The bending moment is calculated using John's formula ($M = \frac{\Delta L}{C}$) where C is a constant based on previous similar designs. The design primary stress is based on the type of steel being used in the hull. As the design of the vessel progresses and the dimensions and weight distribution become more firm the bending moment that the vessel is subjected to is arrived at by balancing the vessel on a trochoidal wave of length equal to the length of the vessel and of height equal to $1.1 \sqrt{LWL}$.

In order to ascertain whether the same vessel would have a lower structural specific weight if its midship section was designed under ABS Rules or in accordance with Navy procedures, it would be convenient to determine which governing set of rules allowed the greatest level of primary bending stress and then assuming the vessel was designed closely to this stress level, it should have the smallest required section modulus and hence the smallest structural specific weight. Unfortunately it is not possible to compare only the allowable stress levels under ABS Rules and in Navy design practice since the stress levels may not be "actual" stresses but rather "stress numerals". It is necessary to also consider the bending

moments obtained under both systems. Table 26 displays a comparison of allowable primary design stresses under ABS Rules and under Navy practices for types of steel with similar yield strengths. As can be seen, the nominal permissible longitudinal bending stress under ABS Rules is a function of ship length. A longer vessel was permitted higher levels of primary stress. The principle behind allowing higher levels of stress as the vessel length increased was based in part on corrosion considerations. The ABS Rules have corrosion allowances incorporated into the scantlings which are arrived at under the Rules. However, the corrosion rate is independent of the thickness of the structural member. Therefore, the same amount of corrosion occurring on a small vessel with thinner plating will impact the structural strength to a greater degree than it would on a larger vessel with thicker material. Hence it is possible to allow greater primary nominal stresses in larger vessels designed to ABS Rules. Under Navy structural design practice there is no corrosion allowance incorporated in the design procedures. The design primary stress is independent of the vessel length and depends only on the material. It is customary to add on a corrosion allowance on Naval hulls to those areas such as the flat keel which sits on the docking blocks and cannot be cleaned and painted as often as the remainder of the hull.[12] Evan's points out that as the corrosion allowance is removed the tendency is for the stress to become independent of vessel length.[17] This being the case the only difference between Navy and ABS is in the magnitude of the allowable "stress".

TABLE 26

COMPARISON OF ALLOWABLE PRIMARY DESIGN STRESSES
UNDER NAVY AND ABS RULES

	NAVY	ABS
Type Steel:	Mild steel	Ordinary strength hull Structural steel (grades A, B, D, E, DS, CS)
Yield Point (psi)	34,000	34,000
Maximum Design Primary Stress (σ_p) in tsi.	8.5	$9.86 \leq \sigma_p \leq 10.56$ $\sigma_p = f(L)$, for $200 \leq L \leq 790$
Type Steel:	HTS	Higher strength hull Structural steels
Yield Point (psi)	47,000	45,500 (grades AH-32, DH-32, EH-32) 51,000 (grades AH-36, DH-36, EH-36)
Maximum Design Primary Stress (σ_p) in tsi.	9.5	$\sigma_p = f(L)$ for $200 \leq L \leq 790$ $12.6 \leq \sigma_p \leq 13.5$ (grades AH, DH, EH-32) $12.9 \leq \sigma_p \leq 13.8$ (grades AH, DH, EH-36)
Type Steel:	HY-80	No equivalent
Yield Point (psi)	80,000	
Maximum Design Primary Stress (σ_p) in tsi.	10.5	

A key to understanding at least a portion of the differences in the allowable stress levels under the ABS and Navy design practices is to examine the nominal bending moments used in both systems. The total longitudinal bending moment under both systems is composed of a still water bending moment and a wave induced bending moment. The still water bending moment is the only portion of the total bending moment that the ship designer can impact significantly once the hull shape is determined. The real difference between the two systems is in the wave induced bending moment and how realistically the shape of the assumed wave approximates that which a vessel of a particular size is likely to encounter. A detailed study is needed to determine the overall effect of the nominal bending moment differences on the allowable stress levels before any definitive statement can be made as to which system allows the greatest level of "actual" stress and therefore would have the smaller section modulus requirement. In the mid 1960's it was a generally accepted fact that closely designed Naval vessels allowed greater levels of stress than merchant vessels.[14] As knowledge about loadings increased ABS Rules have undergone a gradual process of change. It is conceivable that they have narrowed the gap in the allowable "actual" stress levels that existed between Navy and ABS practice. As such the required section modulus under ABS Rules is closer to that required by the Navy.

Under ABS Rules, required scantlings may be reduced when corrosion control techniques are used. The commercial tankers used in this analysis took advantage of this option. However, this practice was not used by the

commercial cargo vessels and this fact helps explain why the structural specific weights of the Navy tankers are not less than those of the commercial tankers as was the case with the Navy and commercial cargo vessels.

A portion of the difference in hull girder structural specific weight can be explained by the type of steel used in the hull girder. Oiler #4 uses only medium steel while Oiler #3 uses medium steel with HY-80 in the stringer plates, sheer strake and bilge strake. Tanker D uses higher strength hull structural steel in the flanges of the hull girder in order to reduce the hull structural weight. The advantage of using the higher strength hull structural steel can be seen by comparing the hull girder weight fractions of Tankers D and E. Both vessels are about the same size but tanker D uses higher strength hull structural steel and tanker E uses ordinary strength hull structural steel.

There are a number of characteristics of the hull girder which impact the hull girder specific weight ratio. Each of the vessels used in this study have a number of characteristics which tend to favor lower structural specific weights and other characteristics which offset this effect.

As the depth of the hull girder at midships is increased, the inertia of the section grows larger and it becomes possible to obtain the necessary midship section modulus with plating thicknesses in the deck and bottom that are reduced relative to a midship section requiring the same section modulus but having less depth. The result is a lower

structural specific weight ratio. Oiler #4 is able to take advantage of this effect. Its hull girder depth is about 25% greater than those of the commercial tankers. If all other parameters of the individual hull forms of the vessels were the same, Oiler #4's structural specific weight would be less. However, Oiler #4 needs a greater hull depth because of the requirement for a second deck within the hull. This deck is not common to the other vessels. In addition there are also numerous platforms or partial decks within the hull that are required primarily for stowage of dry cargo. As can be seen in figure 27, the decks, platforms and flats weight fraction for Oiler #4 is significantly greater than those of the other vessels and is the primary reason why the hull girder specific weight of this vessel is relatively large.

Oiler #3's hull girder depth is only slightly greater than those of the commercial tankers. As such, the greater depth does not have the same effect on the structural specific weight as with Oiler #4. There is a tendency in designing commercial tankers of this size to minimize the depth of the hull girder. These tankers are relatively small by today's standards and are constrained to operate within harbors of a certain depth. Since the draft of the tankers is constrained, any excessive freeboard results in wasted cargo cubic. Freeboards are constrained because of the requirement to meet certain standards of subdivision and stability in the damaged condition. For Oiler #4 there is no tendency to minimize freeboard since the excess hull volume is required for functions other than cargo carrying.

Both Navy oilers have lower block and prismatic coefficients than the commercial tankers. As a result, the Naval tankers have a concentration of displacement amidships. While this tends to favor a lower structural specific weight in the midship region, it is offset to some extent due to the long thin entrance angles required because of the higher speed requirements. This portion of the hull would have a relatively large structural specific weight. This effect has an adverse effect on the structural specific weights of both Naval vessels.

Another difference between the Navy and commercial tankers is in the number of structural bulkheads. The Navy oilers have a larger number of structural bulkheads than the commercial tankers. The effect of this is most pronounced on Oiler #3 where it has a negative impact on the hull girder specific weight ratio and the hull girder weight fraction. The larger number of structural bulkheads is due primarily to the more stringent damage control requirements of the Naval vessels. The impact of the structural bulkheads is less than might have been anticipated because bulkheads designed to Navy specifications are lighter than those designed in accordance with ABS Rules. This reflects a difference in the structural design practice between the Navy and ABS Rules. In general, the Navy structural design practice is to pay more attention to changes in loadings when designing structural members in order to obtain a more efficient structure. While this practice reduces structural weight, it may result in greater hull construction costs since there may be a number of certain sized members which are not in sufficient quantity to allow the shipbuilder to purchase mill runs.[18]

In addition to general design and hull configuration difference there are certain detailed design and construction differences between Navy and commercial practice which have an impact on the hull structural specific weight. General Naval structural design practice has been to use "T" section stiffeners in lieu of angle or flat bar stiffeners as in normal commercial practice. The "T" section is structurally more efficient because of its greater resistance to bending. Its use in lieu of the angle stiffener results in a weight savings but at the price of excessive material wastage and increased hull fabrication cost.

The Navy has recognized the fact that certain Naval structural practices are more costly than normal commercial practice. Oiler #3, which is currently being built for the Navy was to be designed to allow it to be built "in routine commercial yards".[21] The hull structure was originally designed to ABS standards. This design was balanced against Navy structural criteria and several changes were made. The transverse bulkheads were redesigned to Navy specifications to reduce weight. The main deck plating and stiffeners were also redesigned. The flat bar stiffeners were replaced with "T" section stiffeners. The shell plating and longitudinal bulkheads were not changed. As a result, this vessel incorporates both Naval and commercial design practices.

In summary, the hull girder weight fractions of the Naval vessels are greater than those of the commercial vessels primarily because of the hull configuration. Both Navy oilers have a longer length for a given displacement and a greater depth. These characteristics are related

primarily to the greater speed requirement and the larger amount of volume required within the hull of the Navy oilers. The volume requirement has a large effect on oiler #4 where it results in a second deck which is unique to this vessel. The longer length for a given displacement and the greater number of transverse bulkheads has a large impact on the hull girder weight fraction of Oiler #3. The detailed design and construction practices favor the Naval vessels from a weight standpoint but the changes in ABS Rules over the last decade have narrowed the gap which one existed. Navy practices are more costly, however.

The larger weights of the hull girders of the Naval vessels explain about 50% of the difference in structural weight between the Navy and commercial tankers. There are four other reasons which account for the other 50% of the difference in the structural weight fractions between the Naval and commercial tankers.

- Weight of the superstructure
- Weight of masts and kingposts
- Weight of remainder
- Weight of foundations

This effect can be seen in figure 26.

The weight fractions of superstructures for the Naval vessels is from 2-3 times greater than those of the commercial vessels. The reason is that the volumes of the superstructures of the Naval tankers are much greater than those of the commercial vessels because of larger crew sizes, personnel support requirements and military functional volumes. The mast

and kingpost weight fraction is an order of magnitude larger on the Naval tankers but the total impact on full load displacement is small. The Navy tankers need a larger number of kingposts to support the replenishment at sea operations. Commercial vessels have fewer kingposts requiring them primarily for hose handling operations.

The other structural category weight fraction is about twice as great for the Naval vessels. This group includes such items as trunks and enclosures, structural castings, sea chests and welding. The differences in the weights associated with these items are small.

The foundation weight fraction of the Naval tankers is about 2.5 times larger than that of the commercial tankers although the total impact is very small. There are greater foundation weights for the Naval vessels because of the greater amount of auxiliary, electrical, command and control and armament equipment.

From a cost standpoint, hull structure has a greater impact on the Naval vessels for a number of reasons. First, there is more steel in the Naval vessels primarily because of the sizes of the hull girder and the superstructure. Second, the Naval hull form is finer because of the higher speed requirement. The finer hull form is more costly to construct primarily because it requires a greater number of man-hours. This is so because less use can be made of automatic welding processes due to the larger amount of curved plating. Third, there is a greater amount of compartmentation on the Naval vessels which impact labor costs. In general, the productivity of the labor force is reduced somewhat and a greater amount of supervision is required.(18)

As previously mentioned, the use of "T" section stiffeners and the sizing of structural members for anticipated loading as opposed to the commercial practice of using standard size members result in weight savings but at a greater structural cost.

A major source of the construction cost differences between the Navy oilers and the commercial tankers are the inspection and quality assurance standards that are required for the Naval vessels. Due to the scope of this study these aspects were not addressed.

In conclusion, the following observations can be made concerning the structural weights of the Naval and commercial tankers:

- The structural weights of the Naval vessels are greater primarily because the hull girder and superstructure weight fractions of the Navy oilers are much larger. Of secondary importance are the greater weights associated with masts, kingposts, foundations and the remainder group.
- The hull girder weight fractions of the Navy oilers are greater primarily because of the differences in hull configuration between the Navy and commercial tankers.
- The hull configurations are different primarily because of the higher speed requirements of the Navy oilers and because of the amount of volume that is needed within the hull.
- The detailed structural design procedures used by the Navy result in a lower structural weight than those of ABS Rules

but the changes in ABS Rules that have taken place within the last decade have narrowed the gap which once existed between Navy and ABS Rules.

- Hull structural costs of the Navy oilers are greater due to the larger amount of steel required, the hull form and certain detailed design practices used by the Navy.

4.3.2 Main Propulsion

There are a number of differences in the main propulsion area between the Navy oilers and the commercial tankers used in this analysis. One of the obvious differences is in the type of power plant that is used. The oilers are steam powered, while two of the tankers use diesel propulsion and the other uses steam. Table 27 lists the general characteristics of the propulsion plants for each of the vessels. There is a significant difference in the amount of installed power between the Naval and commercial tankers. The main propulsion weight and volume fractions are displayed graphically in figure 28. As can be seen, main propulsion has a greater impact on the Naval vessels in both weight and volume.

Due to the variety of propulsion plants it is not possible to examine each power plant in detail. The analysis therefore will deal with all of the vessels on a broad level in order to identify differences in the weight and volume impact of the main propulsion functional category. The analysis will then be concluded with a more in depth examination of oiler #3 and tanker D. These two vessels were selected because oiler #3

TABLE 27

GENERAL CHARACTERISTICS OF THE MAIN PROPULSION PLANTS -- TANKERS

	Navy #3	Navy #4	D	E	F
SHP					
Commercial Rating Maximum	--	--	15,000	14,000	14,000
Naval Rating Cruising	18,400	28,000	--	--	--
Full Power	24,000	32,000	--	--	--
Type Power Plant	Turbine(1)	Turbines(2)	Turbine(1)	Medium Speed Reversing Geared Diesel	Medium Speed Non-Reversing Diesel
Boilers					
Number	2	3	2	--	--
Suphtr outlet pressure (psi)	600	650	615	--	--
Suphtr outlet temp. (°F)	850	850	905	--	--
Number of Shafts	1	2	1	1	1
Propellor					
Number blades	7	4	5	4	4
Diameter(ft-in)	21-0	20-6	21-6	21-6	21-6
Type	Fixed Pitch	Fixed Pitch	Fixed Pitch	Fixed Pitch	Controllable Pitch
RPM					
Commercial Rating Maximum	--	--	88	90	90
Naval Rating Endurance	92	97	--	--	--
Full Power	100	105	--	--	--

TABLE 27 (cont.)

	Navy #3	Navy #4	D	E	F
Endurance Speed V_e (knots)	20	20	16.0	16.0	16.0
Speed at Full Power (knots)	20+	20+	--	--	--
Range	6,000	6,500	12,000	12,000	12,000

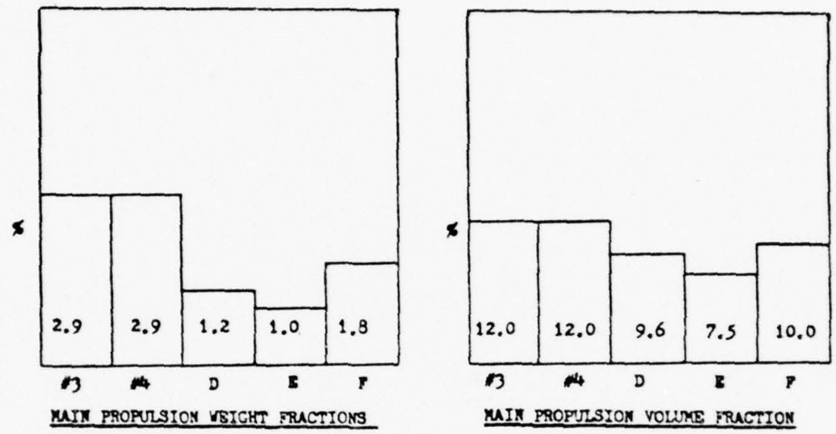


FIGURE 28 Main Propulsion Weight and Volume Fractions - Tankers

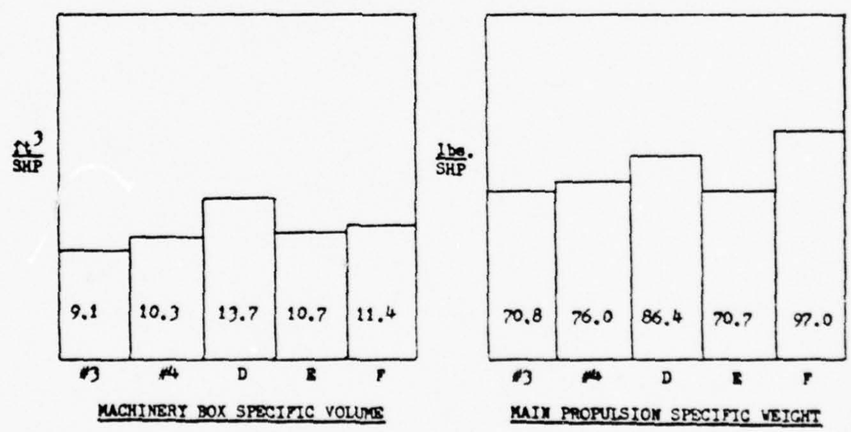


FIGURE 29 Main Propulsion Specific Ratios - Tankers

is a current Navy design and tanker D is a very recent commercial design. Both vessels use a steam driven turbine for propulsion.

The largest impact of main propulsion is in volume. The main propulsion volume fractions of the Naval vessels are about 30% greater than those of the commercial vessels. It is difficult to draw conclusions based on this fact alone since there is such a wide variance in ship size as measured by total internal volume and full load displacement. In terms of cubic feet, the volume of the machinery box of oiler #3 is only slightly greater than that of tanker D. The machinery box of tanker E is only slightly greater than that of tanker F. It is necessary therefore to examine the machinery box specific volume. The machinery box volume is the volume of main propulsion less the volume of the stack and the volume of the uptakes which do not contain propulsion support equipment. Figure 29 includes a graphical representation of machinery box specific volume. There are a number of observations that can be made with respect to this figure.

- The specific volumes of the Naval vessels are less than those of the commercial tankers.
- The specific volume of oiler #4 is greater than oiler #3 because it is a twin screw vessel and has three boilers.
- The installed shaft horsepowers of the commercial tankers are all about the same but the specific volumes of the two diesel powered tankers E and F are about 25% less than that of tanker D which is a steam plant.

- The most interesting comparison is between oiler #3 and tanker D. Both vessels devote about the same amount of volume to main propulsion but the oiler has a 24,000 SHP plant and tanker D has a 15,000 SHP plant.

It appears then that based on these vessels, the machinery boxes on the Naval vessels are more tightly packed than those of the commercial tankers. In addition, the Naval vessels have a larger amount of electrical and auxiliary equipment within the machinery box. It is interesting to note that because of damage control considerations, the Naval vessels are forced to have the propulsion plant divided into two watertight compartments.

In order to examine the weight impact of main propulsion, it is useful to explain the weight fraction as the product of the main propulsion specific weight and the propulsion capacity/ship size ratio. The mathematics of this relationship are revealed in table 28.

Three statements can be made with regard to table 28. First, the main propulsion weight fractions for the Navy oilers are about twice as large as those of the commercial tankers. Second, the propulsion specific weights of the Navy oilers are about 15%-20% less than those of the tankers, and third, the propulsion capacity/ship size ratios of the Naval vessels are from two to three times larger than those of the tankers.

The primary reason the Navy oilers have a larger propulsion capacity/ship size ratio is because of the greater speed requirement. The tankers are designed for a service speed of 16 knots. The oilers

TABLE 28

TANKER MAIN PROPULSION WEIGHT FRACTION EXPRESSED AS THE PRODUCT OF THE PROPULSION SPECIFIC WEIGHT AND THE PROPULSION CAPACITY/SHIP SIZE RATIO

Vessel	Main Propulsion Weight Fraction x 100 (%)	=	Propulsion Specific Weight (lbs/SHP)	x	Propulsion Capacity/Size Ratio (SHP/ton)	x	Conversion Factor (1 ton/2240 lbs)
Navy #3	2.87		71.7		0.90		1/2240
Navy #4	2.88		76.0		0.86		1/2240
D	1.22		86.4		0.32		1/2240
E	1.0		70.7		0.32		1/2240
F	1.78		97.1		0.41		1/2240

have a 20 knot cruising speed. This 4 knot speed advantage for the Navy not only requires that the propulsion plant be larger but also that the hull form be much finer.

The main propulsion specific weight is illustrated graphically in figure 29. It is useful to examine the propulsion specific weight because it reveals the price in weight that the designer must pay for the installed power of the propulsion plant. The specific weight may reveal differences in design practice between the Naval and commercial designer but it may also be influenced by other factors such as the rated horsepower of the plant and the physical layout of the plant. The main propulsion specific weights for the Naval vessels are about 15-20% less than those of the commercial tankers. This difference appears small when considering that the specific weights of the Navy cargo vessels were on the order of 35% less than those of the commercial cargo vessels. With the cargo vessels, an economy of size effect was present. With the tankers the economy of size effect seems to have been reduced somewhat. In order to examine this parameter more closely it is useful to divide the propulsion specific weight into the following categories:

- Energy generation and propulsion unit specific ratio
- Propulsor specific ratio
- Propulsion support specific ratio

The values of these specific ratios are illustrated graphically in figure 30. As can be seen, the energy generation and propulsion unit specific ratios of the Naval vessels are generally less than those of the tankers.

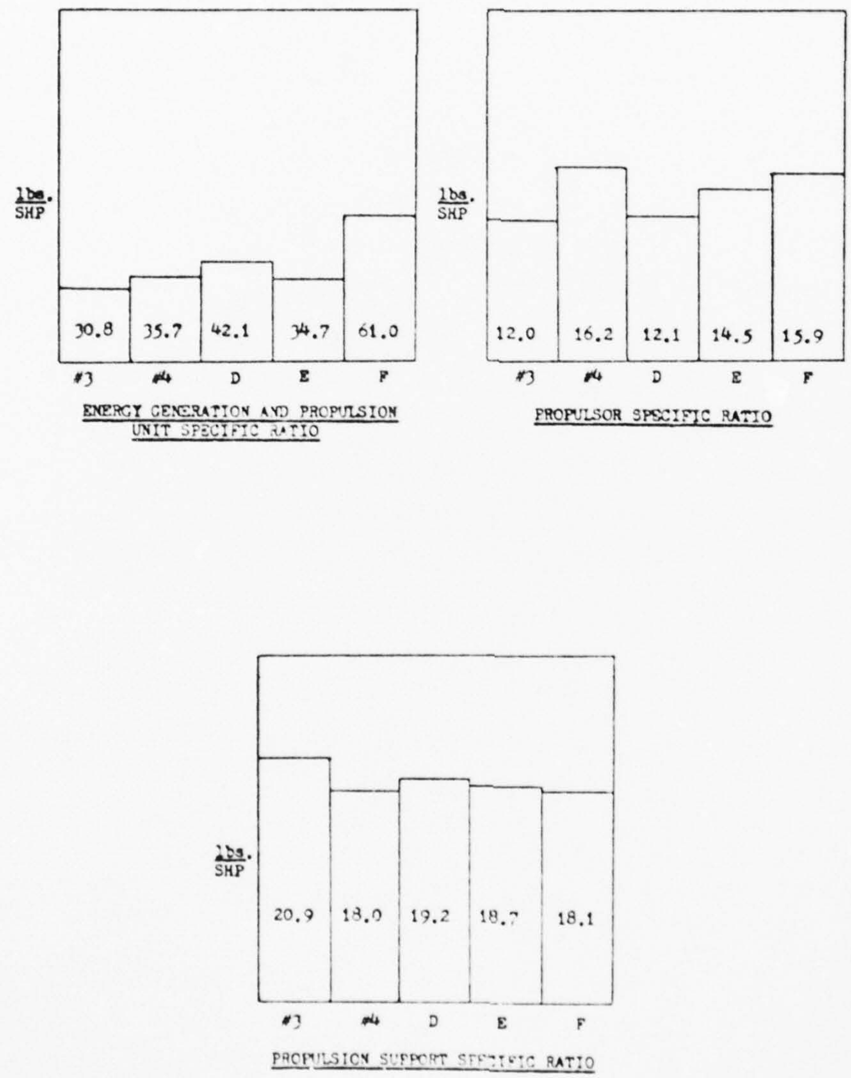


FIGURE 30 Main Propulsion Subgroup Specific Weights - Tankers

Navy #3's is less than Navy #4's because #4 is a twin screw plant and because Navy #4 has a third boiler which is needed for full power operations. The energy generation and propulsion unit specific ratios of the Naval vessels are less than tanker D's primarily because of an economy of size effect. Tankers E and F are both diesel powered. Both of the propulsion plants of these tankers have the same rated capacity. Tanker F's specific weight is much larger because its diesel engine and its reduction gears are much heavier.

Figure 30 also displays the propulsor specific ratios. The weight is comprised of shafting, bearings and propellers. There is very little economy of size effect present because Navy #4 has two shafts and although the machinery box is located aft, the shaft run is about 75% longer than those of the commercial tankers. The shaft run for Navy #3 is also considerably greater than that of the commercial tankers.

The propulsion support specific ratios do not vary significantly from vessel to vessel. There is no economy of size effect present. One of the reasons for this is that tankers E and F are diesel powered and there are a number of propulsion support subsystems that are not required that are required for steam plants. This graphical representation of the propulsion support specific weights indicates that from a weight standpoint the Naval vessels carry more propulsion support equipment.

In summary, the main propulsion specific weights of the Naval vessels exhibit an economy of size trend only with respect to the energy generation and propulsion unit specific ratios. The economy of size effect

is missing from the propulsor specific weight because of the heavier shafting weights. There is also no economy of size effect associated with the propulsion support specific ratio.

In order to identify some of the differences in propulsion design practices used by Naval auxiliary and commercial designers it is helpful to examine both a Navy and commercial design in greater detail. This analysis will deal with the Navy oiler #3 and with tanker D. Figures 31 and 32 display a simplified main propulsion block diagram for each of these vessels. The propulsion plant will be divided into three sections.

- Steam generation
- Main engines
- Propulsion support equipment

<u>Steam generation</u> is accomplished on both vessels with two boilers utilizing two stages of feed heating. The Naval boilers have a design overload of 120% while tanker D has only a 106% overload.

The <u>main engines</u> on both vessels are powered by a single cross compounded HP-LP steam turbine. There is a significant difference in the rated capacity of the main engines. Oiler #3's main engine is rated at 24,000 SHP for full power and tanker B's have a maximum ABS power rating of 15,000 SHP.

The <u>propulsion support equipment</u> is comprised of the following equipment:

- Main condenser and air ejector
- Combustion air supply system

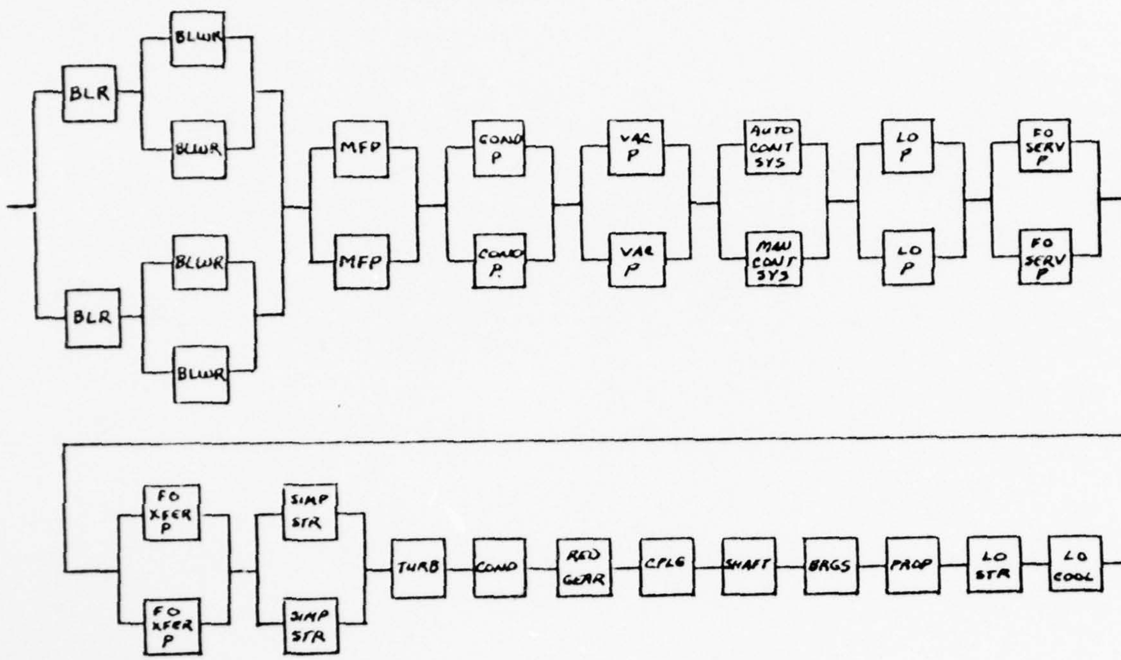


FIGURE 31 Simplified Propulsion Block Diagram - Oiler #3

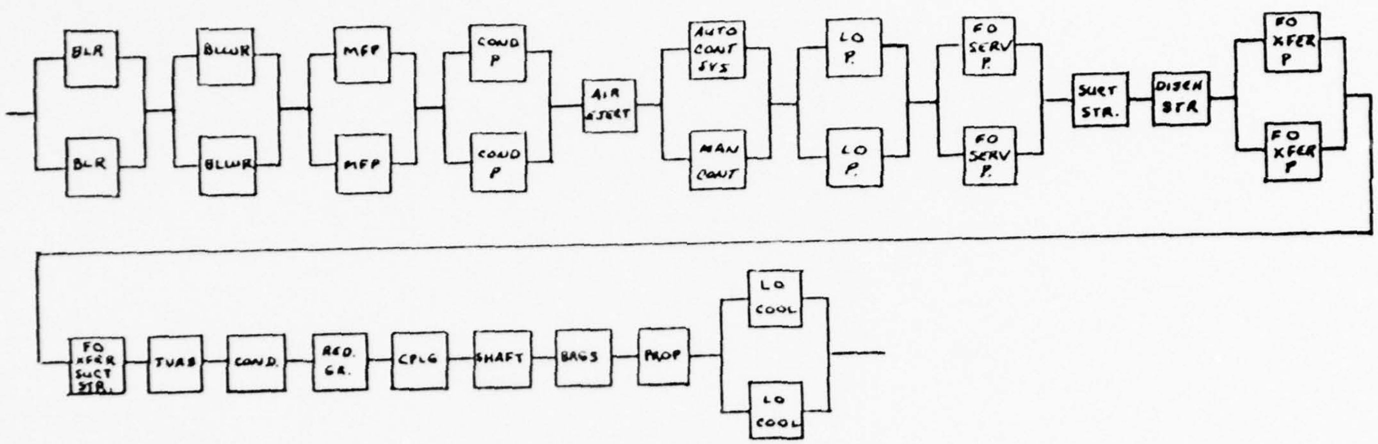


FIGURE 32 Simplified Propulsion Block Diagram - Tanker D

•Propulsion control equipment

•Main steam system

•Feedwater and condensate system

•Circulating and cooling system

•Fuel oil service system

•Lube oil service system

The propulsion support equipment makes up a significant percentage of the main propulsion weight.

	Percentage of Main Propulsion Weight
Oiler #3	29.6
Tanker D	22.3

In order to determine why the percentage of main propulsion weight taken by propulsion support equipment is greater for the Navy oiler, it is helpful to have the percentage of main propulsion weight for each of the propulsion support groups.

Propulsion Support Group	Percentage of Main Propulsion Weight	
	Navy #3	Tanker D
Main condenser and air ejector	6.1	5.0
Combustion air supply	2.0	1.0
Propulsion control equipment	4.2	0.6
Main steam system	2.8	2.0
Feedwater and condensate system	5.1	3.7
Circulating and cooling system	4.9	3.0
Fuel oil service system	0.6	1.7
Lube oil service system	1.9	3.3

Significant differences in each propulsion support group between the Navy oiler and the commercial tankers will be identified.

Both vessels use a single pass main condenser. Oiler #3 utilizes scoop injection while tanker D does not. Oiler #3 makes use of vacuum pumps in lieu of air ejectors. Oiler #3 has two vacuum pumps and tanker D has one air ejector.

The combustion air supply system is more elaborate on the Naval vessel. Oiler #3 has two electric forced draft blowers per boiler while tanker D has only one. Each of the two forced draft blowers on the Naval vessel is capable of providing the air requirements from standby to full power.[19] This additional performance capability of the Navy oiler impacts acquisition cost and the amount of machinery volume that is needed.

Both vessels have made use of centralized propulsion plant control. Both vessels have a central control station and pilothouse throttle control. There are provisions for casualty control such as remote manual control and local manual control. The weight associated with the oiler's control system is much greater than that of tanker D's. This is the result of the larger amount of propulsion support equipment on the Naval vessel.

There are no significant differences in the main steam systems.

Both vessels have two turbine driven main feed pumps and two electric main condensate pumps. Navy specifications call for the use of seamless copper piping in the condensate system while commercial specifications allow the use of carbon steel piping. The copper piping is

significantly more expensive than carbon steel piping. The feedwater and condensate system weight for the Navy oiler is larger because of the greater amount of piping required due to the layout of the main propulsion spaces.

Tanker D employs a closed fresh water system for circulating and cooling of auxiliaries. Navy practice is to use salt water cooling of auxiliaries which necessitates copper-nickel piping, a high cost item.

Both vessels have two fuel oil service pumps of which only one is required at any one time to supply both boilers. The other pump is kept in standby. The most significant difference between the two vessels is that tanker D takes suction directly from one of the three fuel oil bunker tanks while the Navy oiler utilizes fuel oil service tanks located in the fire room. The greater amount of weight associated with the fuel oil service system of tanker D is the result of fuel oil service piping. This vessel has a fuel tank forward while the oiler's tanks are located adjacent to the machinery space.

There are no significant differences in the lube oil service system.

From a cost standpoint, the main propulsion functional group has a greater impact on the Navy oilers for several reasons. First, the greater speed requirements of the Naval vessels require much larger main propulsion plants. Second, the Navy oilers have more extensive propulsion support equipment and have certain practices with regards to propulsion support equipment that involve increased costs over that which would be involved if commercial practice was adopted.

In summary, the following observations and conclusion can be stated with regards to the main propulsion functional category:

- Main propulsion has a greater impact on the Naval vessels from both a weight and volume standpoint. The volume impact predominates.
- The horsepower capacities of the Naval propulsion plants are much larger due to the greater speed requirements. The greater speed requirement reflects the military nature of the Navy oilers and forces the hull form of the Navy oilers to be much finer than those of the commercial tankers. This characteristic has an adverse effect on structural weight and hull construction costs.
- The propulsion specific volumes are less for the Naval plants which indicates that the machinery boxes on the Naval vessels are more tightly packed with equipment than the commercial tankers.
- The Navy oilers have more propulsion support equipment than the commercial tankers. Certain detailed propulsion practices used by the Navy have a negative impact on the cost of the subsystems.
- More stringent damage control criteria force the Naval vessels to have two main propulsion compartments.

4.3.3 Electrical

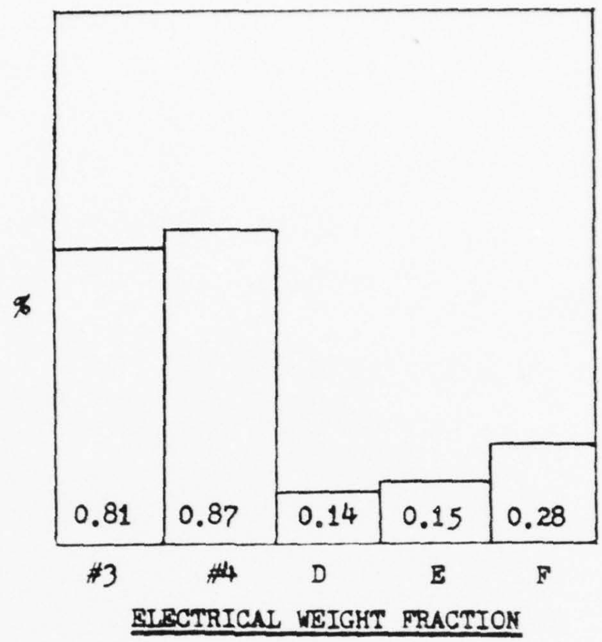
There are significant differences in the design criteria and performance requirements of the electrical systems installed on the Navy oilers as compared to those on commercial tankers. Table 29 lists the installed electrical capacity of each of the vessels. The electrical weight and volume fractions are displayed in figure 33. While the weight and volume fractions of the Naval vessels are significantly greater than those of the commercial tankers, the impact of electrical systems on the full load displacement and the total internal volume is very small. The electrical volume fraction is misleading in the sense that it does not include the volume of the machinery box occupied by the electrical generators and the ancillary equipment. This volume is substantial and explains in part why the machinery boxes of the Navy oilers are tightly packed with equipment.

In order to highlight the differences in the electrical functional category between the Naval and commercial tankers it is helpful to examine the electrical weight fraction more closely. This parameter can be explained as the product of two quantities; the electrical specific weight and the electrical capacity/ship size ratio. Table 30 reveals the mathematics of this relationship. These two factors, which when multiplied together give the electrical weight fraction, are not independent of each other. There may be a certain amount of coupling between the two terms. However, this technique, when used with care, is useful in analyzing the differences between vessels. Two observations can be made with respect to table 30.

TABLE 29

INSTALLED ELECTRICAL CAPACITIES -- TANKERS

	Number of Generators	Capacity	Type
Navy #3	3	2500 KW	SSTG (steam)
	1	750 KW	Emerg Diesel
Total		8250 KW	
Navy #4	4	2000 KW	SSTG (steam)
	1	500 KW	Emerg Diesel
Total		8500 KW	
D	1	1000 KW	SSTG (steam)
	1	750 KW	Aux Diesel
	1	200 KW	Emerg Diesel
Total		1950 KW	
E	2	600 KW	Diesel Gen
	1	100 KW	Emerg Diesel
Total		1300 KW	
F	2	1000 KW	Diesel Gen
	1	600 KW	Generator attached to main gear box
	1	150 KW	Emerg Diesel
Total		2750 KW	



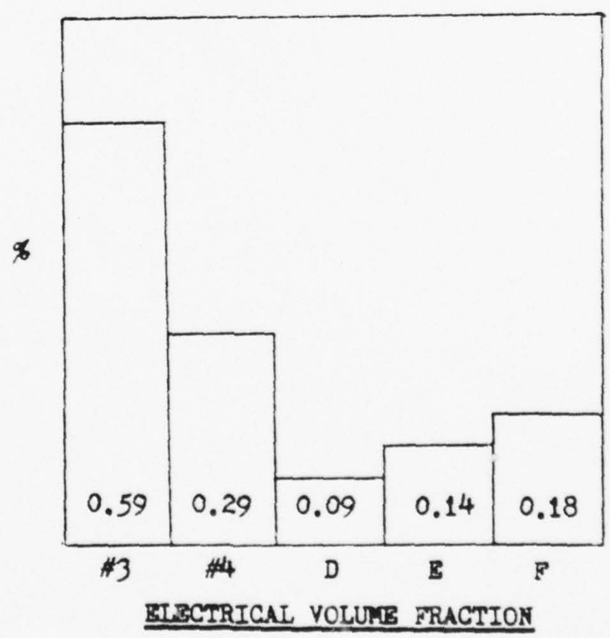


FIGURE 33 Electric Weight And Volume Fractions - Tankers

TABLE 30

TANKERS' ELECTRICAL WEIGHT FRACTIONS EXPRESSED AS THE PRODUCT OF THE ELECTRICAL SPECIFIC WEIGHT AND THE ELECTRICAL CAPACITY/SHIP SIZE RATIO

Vessel	Electrical Weight Fraction x 100 (%)	=	Electrical Specific Weight (lbs/KW)	x	Electrical Capacity/Ship Size (KW/ton)	x	Conversion Factor (1 ton/2240 lbs)
Navy #3	0.81		58.0		0.31		1/2240
Navy #4	0.87		86.1		0.23		1/2240
D	0.14		74.7		0.04		1/2240
E	0.15		113.3		0.03		1/2240
F	0.28		78.1		0.08		1/2240

- The electrical specific weights vary from vessel to vessel. The reason is not obvious.
- The installed electrical capacity/ship size ratios of the Naval vessels are significantly greater than those of the commercial tankers.

Each of these observations will be discussed in sequence.

In order to analyze the difference in electrical specific weights it is necessary to subdivide the electrical weight into four groups.

- Electric power generation
- Power distribution (switchboards)
- Power distribution (cable)
- Lighting system

Figure 34 is a graphical representation of the specific weights associated with each of these groups.

The electric power generation specific weight is interesting in the sense that the economy of size effect that was noted with the cargo vessels seems to be missing. The issue here is clouded because of the fact that tankers E and F use diesel driven generators and tanker D uses a combination of steam and diesel driven generators. The Naval vessels use steam driven generators.

In order to assess the effect of diesel driven generators versus steam driven generators, it is useful to compare the installed electrical capacity and the electric power generation specific weights of the tankers against those of the cargo vessels.

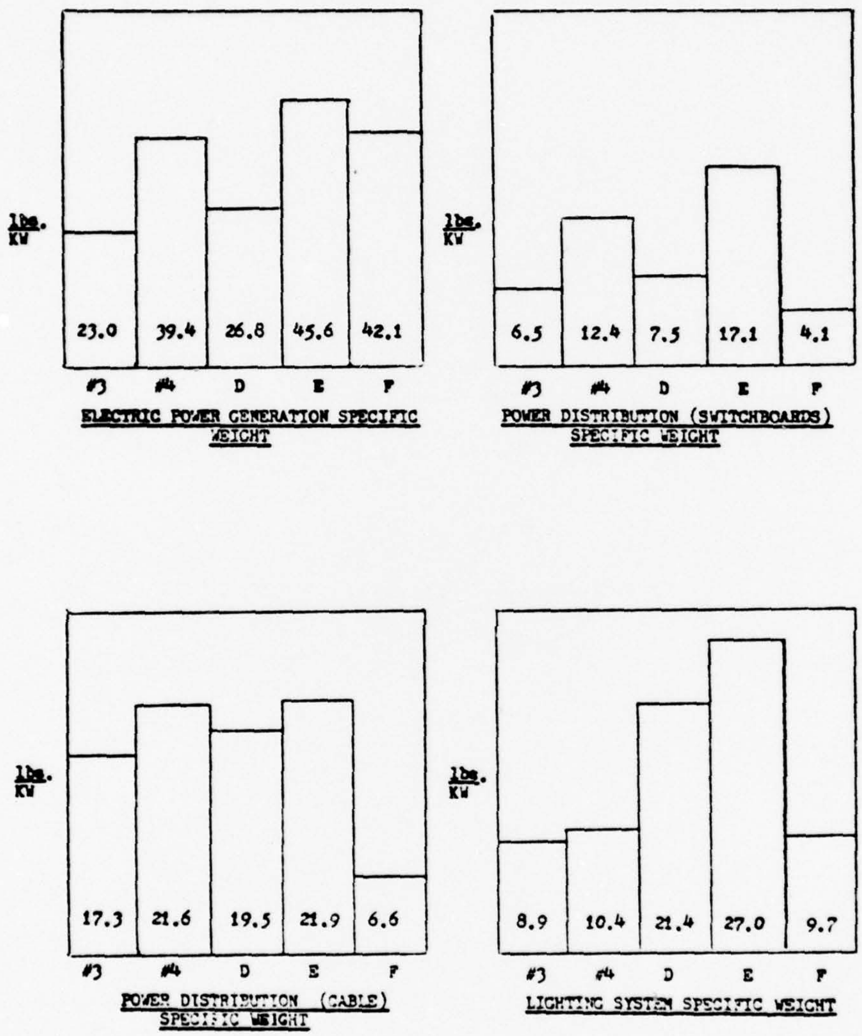


FIGURE 34 Electrical Subgroup Specific Weights - Tankers

Vessel	Installed Electrical Capacity (KW)	Electric Power Generation Specific Weight
Cargo A	1300	87.0
B	2600	49.0
C	1650	70.7
Tanker D	1950	26.8
E	1300	45.6
F	2750	42.1

As can be seen, while the installed electrical capacities do not vary considerably, the electric power generation specific weights of the tankers are significantly less. Comparing cargo A and tanker E will emphasis this point. Both vessels have a 1300 KW capacity which is obtained by using two 600 KW generators and one 100 KW emergency generator. Cargo vessel A's main generators are steam driven while tanker E's are diesel driven. The electric power generation specific weight of tanker E is about one half that of vessel A's. This explains why the economy of size effect is missing from the electric power generation specific weight figure for the tankers and why it was present with the cargo vessels.

One other interesting difference between the Naval vessels and tanker D in this area deserves mention. The SSTG on the commercial tanker D does not have a separate condenser as is the practice on these Naval vessels.

There are no significant differences in terms of the number of switchboards for power distribution. All the oilers and tankers have one main switchboard and one emergency switchboard.

There is no economy of size effect associated with the power distribution (cable) specific weights as might have been expected because the Naval vessels have a greater number of power distribution systems and a larger amount of subdivision. The commercial vessels have two distribution systems; a normal and an emergency distribution system. The Navy oilers have four types of distribution systems:

- Ship's service power distribution
- Emergency power distribution
- Casualty power distribution
- Special power distribution

The lighting system specific weights of the Naval vessels are less because of an economy of size effect. The actual weight of the lighting systems on the Naval vessels are greater than those on the commercial vessels but because of the greater electrical capacity, the specific weights are less.

The electrical capacities/ship size ratios of the Naval oilers are about five times as great as those of the commercial tankers. There are two primary reasons why the installed electrical capacities are so much larger for the Naval vessels. First, the Naval vessels most demanding electrical operating condition requires about 2.5 times as much electrical power as the most demanding operating condition for commercial tankers. Second, the Navy's electrical design criteria for sizing generators results in a greater installed capacity.

The Navy's most demanding electrical operating condition is during replenishment-at-sea operations. The most demanding electrical operating condition for two of the commercial tankers is during offloading operations in port. Tanker D's most demanding electrical operating condition is at sea.

The Naval and the commercial designers use basically the same type of load power analysis to determine the most demanding electrical operating condition. The commercial practice is to check two operating conditions; the maximum sea operating condition and the maximum port operating condition. The Naval practice is to check a number of conditions depending on vessel type. The conditions include anchor, cruising, replenishment, battle, and shore. The specifics of assigning a load factor to each piece of electrical equipment for each operating condition to determine the maximum electrical load are the same for the Naval and commercial designers.

It is usually the practice of the Navy to include a 20% growth margin for auxiliary type vessels. The Maritime Administration encourages commercial owners to include a 20% growth margin but it is not required. Once the electrical loads for each of the operating conditions are established, the Navy's practice is to require that the load for the maximum operating condition be carried with any one of the generating sets in reserve. Commercial practice is governed by the Coast Guard Engineering Regulations.(16) These regulations require in part that all ocean going vessels using electricity for ship's service power or light shall have at least two ship's service generating sets, the capacity of which will be

such that the at-sea load can be met with one generating set in reserve. The at sea load is not the most demanding electrical load for tankers E and F. As a result, this difference contributes somewhat to the difference in installed electrical capacity between the Naval and commercial tankers.

Coast Guard regulations also permit a system which utilizes a large steam turbogenerator designed for continuous operation and a smaller automatically started auxiliary generator. Tanker D makes use of this type of system.

The dollar cost of the electrical functional category would be much greater for the Naval oilers for a number of reasons. First the installed electrical power is much greater. There are a greater number of generators and each has a greater capacity. The power distribution system is more elaborate. The labor costs would be greater because of the greater amount of equipment and the larger amount of subdivision within the hull and superstructure.

The emergency generating capacities of the Naval vessels are greater because of the more stringent criteria for sizing the generators. Naval practice is to require that the emergency generators carry emergency ship control plus one half of the ship ordnance load or the cold propulsion plant start.[20] Coast Guard regulations state that the emergency loads that must be carried are:

- Minimum lighting for safety and corrective maintenance
- Essential damage control equipment
- Essential navigation and communication subsystems

The emergency load condition is about ten times greater on the Naval vessels.

In summary there are a number of conclusions that can be made concerning the electrical functional comparison between the Navy oilers and the commercial tankers:

- The installed electrical capacity is a vital part of the underway replenishment capability and the amount of power required for the underway replenishment condition is primarily responsible for the difference in installed electrical capacity between the Naval and commercial tankers.
- The installed electrical capacities of the Naval vessels are about four times larger than those of the commercial vessels.
- In terms of weight, the impact of the electrical systems, although greater on the Naval vessels, is very small.
- The volume impact of electrical systems is felt mainly in the machinery box of the Naval vessels.
- The Navy oilers are required to have greater redundancy in the power distribution system. This reflects the military nature of these vessels.
- There are minor differences in the generating sizing criteria which explain a portion of the difference in total installed capacity.
- The emergency generators are larger on the Naval vessels because of the greater number of emergency loads.
- The cost of the electrical systems on the Naval vessels is much greater.

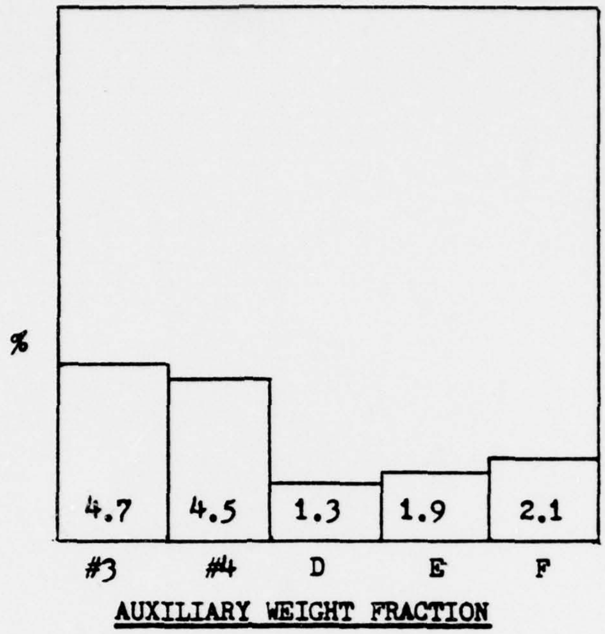
4.3.4 Auxiliary

The auxiliary functional group has a considerably greater impact on the Naval oilers than on the commercial tankers. The influence of the auxiliary systems is felt primarily in terms of required volume. Figure 35 displays the auxiliary weight and volume fractions. As can be seen, the auxiliary volume fractions of the Naval vessels are significantly greater than those of the commercial vessels. The auxiliary weight fractions of the Naval vessels are twice as large as those of the commercial tankers but the magnitudes of the auxiliary weight fractions of the Naval vessels are small.

In order to determine why the auxiliary volume fractions of the Naval vessels are so large it is necessary to divide auxiliary volumes into five groups.

- Cargo handling
- Auxiliary services
- Cargo offices and shops
- Auxiliary systems and equipment
- Deck auxiliaries

Auxiliary services and cargo offices and shops have negligible volume impact. Figure 36 displays the volume fractions of the remaining three auxiliary volume subgroups. As can be seen, the volume fractions for all three groups are greater for the Naval vessels, with the cargo handling volume being the most significant.



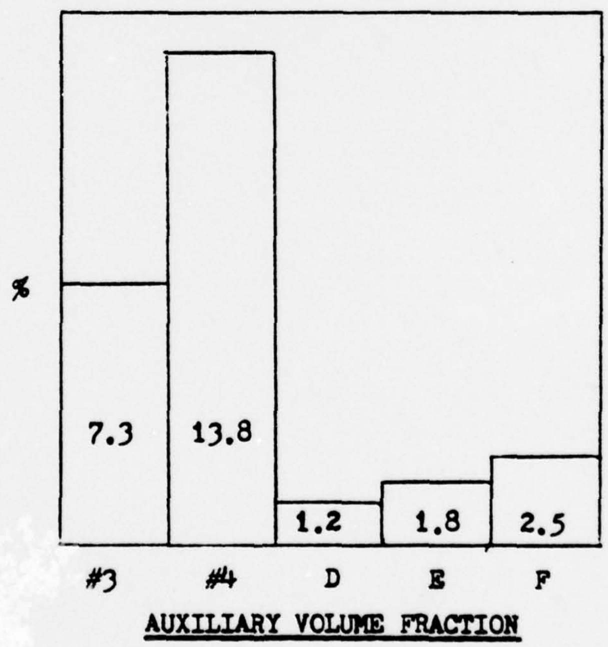


FIGURE 35 Auxiliary Weight And Volume Fractions - Tankers

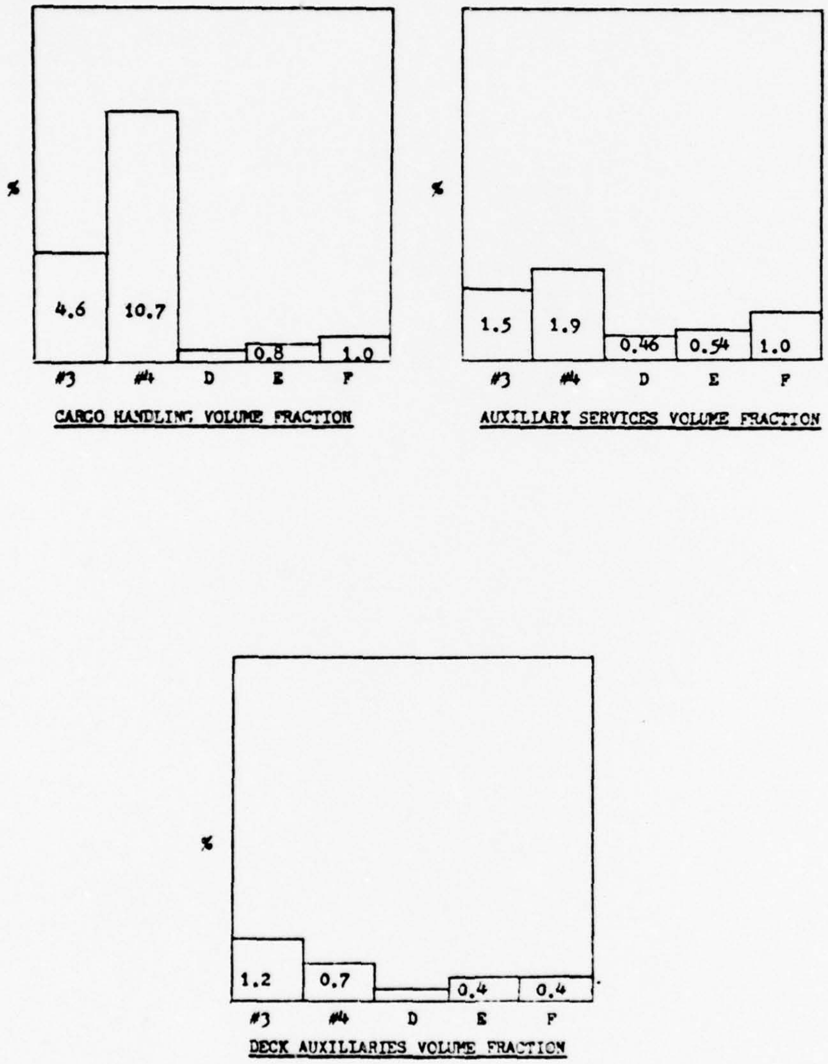


FIGURE 36 Auxiliary Subgroup Volume Fractions - Tankers

The oiler Navy #4 has a relative large cargo handling volume fraction because it carries dry stores and cargo ammunition as well as petroleum products. The cargo handling volume differences between Navy #3 and Navy #4 are due to the amount of space dedicated to elevators and cargo staging areas. Navy #3 carries only a small amount of stores as it is primarily a petroleum replenishment ship. There is a difference between the Naval and commercial tankers in the amount of volume devoted to liquid cargo control. This is due to the fact that the Naval vessels have a greater number of cargo oil pumps with a larger total capacity than the commercial vessels.

The auxiliary services and the deck auxiliaries volume fractions of the Naval vessels are about twice those of the commercial tankers but the magnitudes of each of these volumes are of secondary importance in explaining the differences in the auxiliary volume fraction. The auxiliary services volume fractions of the Navy oilers are greater because of the large ventilation and air conditioning systems which are necessitated by the larger crew size and the increased amount of subdivision. The deck auxiliaries volume fraction is larger because of the amount of space dedicated to maintenance and storage of the transfer at sea equipment.

In order to determine the reason for the larger auxiliary weight fractions of the Navy oilers, it is necessary to subdivide the auxiliary functional weight as follows:

- Climate control system
- Sea water systems
- Fresh water systems

- Fuels and lubricants systems
- Air, gas and miscellaneous fluids
- Ship control systems
- Underway replenishment systems
- Mechanical handling systems
- Auxiliary repair parts

The weights of these subgroups are divided by the full load displacement to obtain specific weights. The units are lbs/ton. Figure 37 is a graphic representation of each of these specific weights. Two general observations can be made from this display.

- With the exception of the fuels and lubricant systems specific weights, the specific weights of the subsystems on the Naval vessels are much greater.
- As would be expected, the difference in underway replenishment systems specific weights is substantial.

The underway replenishment system is comprised of the cargo and load handling equipment, rigging and blocks, and deck machinery needed to transfer cargo at sea. Table 23 in Section 4.1 displays the number of transfer stations for each of the vessels. The large difference is transfer capability reflects the difference in the mission of the Naval and commercial tankers.

The mechanical handling system specific weights of the Naval vessels are about 75% greater than those of the commercial vessels. The group is composed of winches, capstans, cranes and anchor handling equipment. The difference in weight is due primarily to the large number of winches carried by the Naval vessels for the underway replenishment capability.

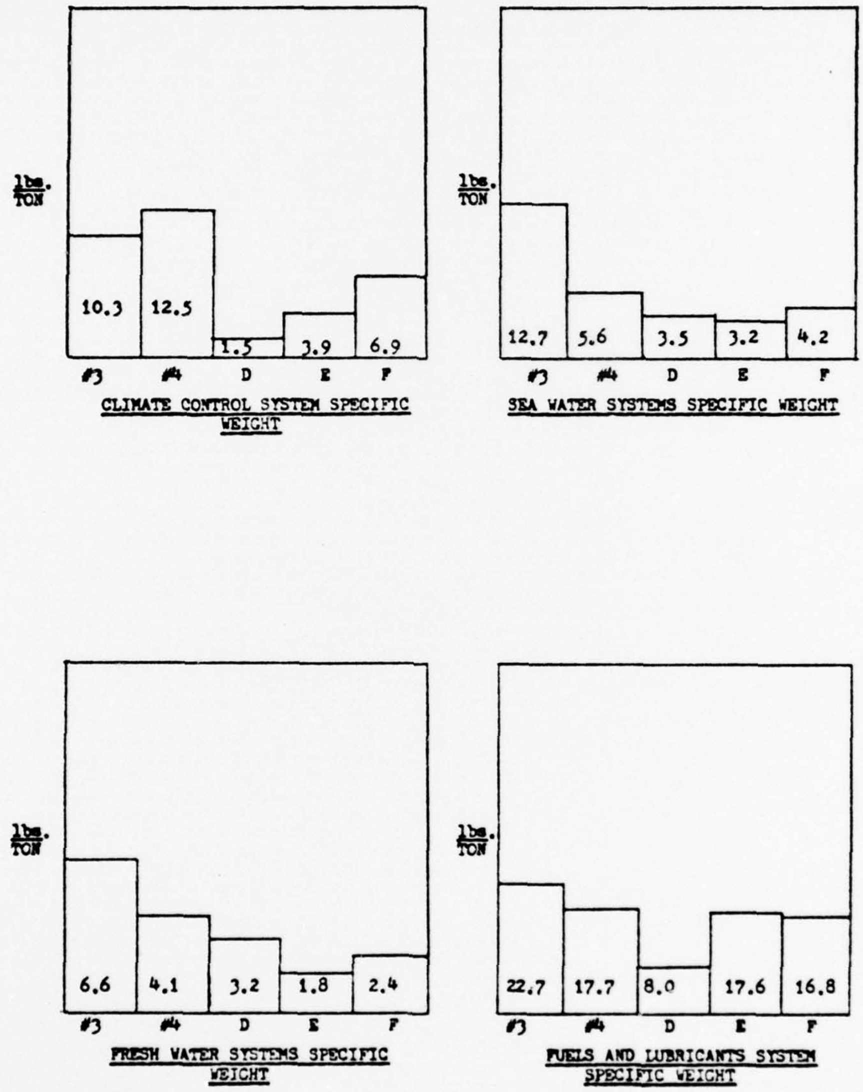
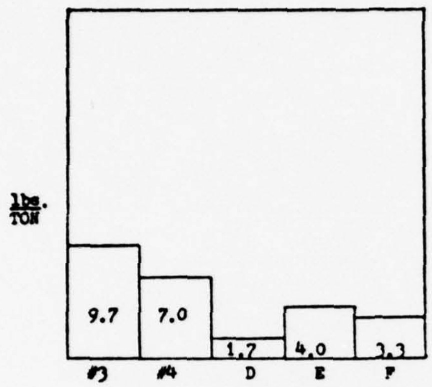
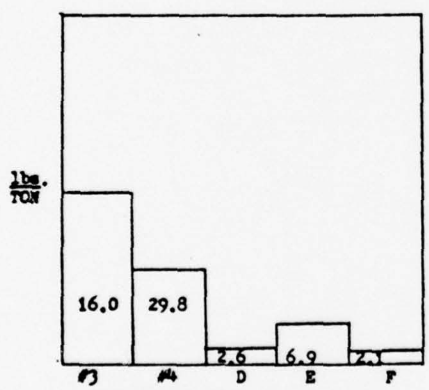


FIGURE 37 Auxiliary Specific Weights - Tankers

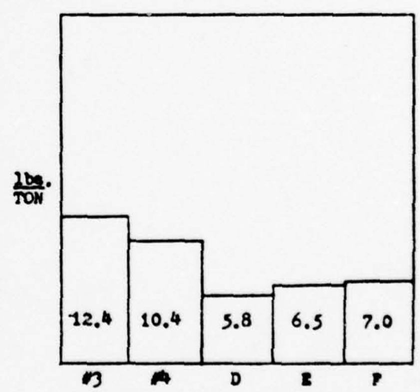


AIR, GAS AND MISCELLANEOUS FLUID SYSTEM SPECIFIC WEIGHT

SHIP CONTROL SYSTEMS SPECIFIC WEIGHT



UNDERWAY REPLENISHMENT SYSTEM SPECIFIC WEIGHT



MECHANICAL HANDLING SYSTEM SPECIFIC WEIGHT

FIGURE 37 - Continued

The climate control system specific weights of the Naval vessels are larger because of the greater crew size and the amount of compartmentation.

The sea water system specific weights of the Naval vessels are greater primarily because of the weight associated with firemains, flushing, sprinklers and salt water service systems. This weight category is smaller for the commercial tankers primarily because they use a fresh water sanitary flushing system, have no magazine sprinkling system, no countermeasure washdown system, no decontamination stations and a much smaller crew size.

The fresh water systems specific weight is larger for the Naval vessels primarily due to large freshwater subsystems and the larger distilling plants. These subsystems are larger because of the greater crew size. The distilling capacity per day is listed below.

Vessel	Distilling Capacity (gallons per day)
Navy #3	24,000
Navy #4	40,000
D	16,000
E	5,000
F	5,000

The air, gas and miscellaneous fluid system weight is comprised of the following subgroups:

•Gas, HEAF, cargo piping, O_2-N_2, aviation lube oil (20%)

•Fire extinguishing system

•Compressed air system

•Miscellaneous piping systems

The weights associated with fire extinguishing systems and compressed air systems are responsible for the difference in the specific weight. Fire extinguishing systems are larger on the Naval vessels because of the larger installed CO_2 system and the greater number of fire stations. The CO_2 system is larger because of the number of pump rooms, more extensive compartmentation, and because a CO_2 system is not required in the engine room on commercial tankers. The compressed air system is larger on the Naval vessels because the underway replenishment capability requires a high pressure air system which is not required on commercial tankers. The ship service air system is more extensive aboard the Naval vessels because of the military payload and the larger maintenance facilities.

The ship control system weights are comprised of the weights of the steering gear system and the rudder. The majority of the specific weight difference is due to the weight of the rudder. Navy #4 is a twin screw vessel with two rudders while Navy #3 has one rudder with a surface area much larger than commonly used in normal commercial practice in order to aid in maneuvering during replenishment in close operation.

From a cost standpoint, the auxiliary functional group would be more expensive for the Naval vessels than for commercial vessels. The subsystems which make up the auxiliary functional groups on the Naval

vessels are more extensive or have greater capability than those installed on the commercial vessels and as such the cost of these subsystems would be larger.

In summary the following observations can be made concerning the auxiliary functional category:

- The weight and volume impact of the auxiliary functional group is greater on the Naval oilers.
- The auxiliary volume requirement is the largest single factor which contributes to the difference in total ship volume between the Naval and commercial tankers.
- The impact of auxiliary volume is so great primarily due to the amount of space dedicated to cargo handling. The requirement for cargo handling volume is greater on the replenishment oiler because it carries dry cargo and cargo ammunition in addition to petroleum based cargo. The amount of volume dedicated to liquid cargo handling is greater because of the larger pumping capacity of the Naval vessels.
- The auxiliary weight fractions of the Naval oilers are about twice as large as those of the commercial tankers. A significant portion of the difference in weight is the result of the numerous auxiliary subsystems which give the Naval vessels an underway replenishment capability. These systems include the transfer equipment, mechanical handling equipment, the HP air system and the larger rudders installed on the Naval vessels.

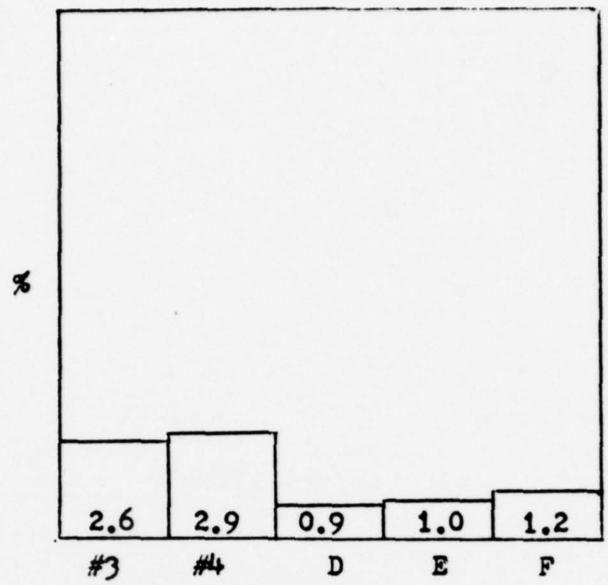
- The remainder of the weight difference is attributable to either the indirect impact of the underway replenishment capability or to the military nature of the Naval vessels. The underway replenishment capability impacts crew size which in turn effects the climate control system and the fresh water system. The fact that the Naval vessels may have to carry out their mission in a limited war environment establishes a unique requirement for more elaborate fire extinguishing equipment, a countermeasure washdown system and a number of decontamination stations.

4.3.5 Other Ship Operations

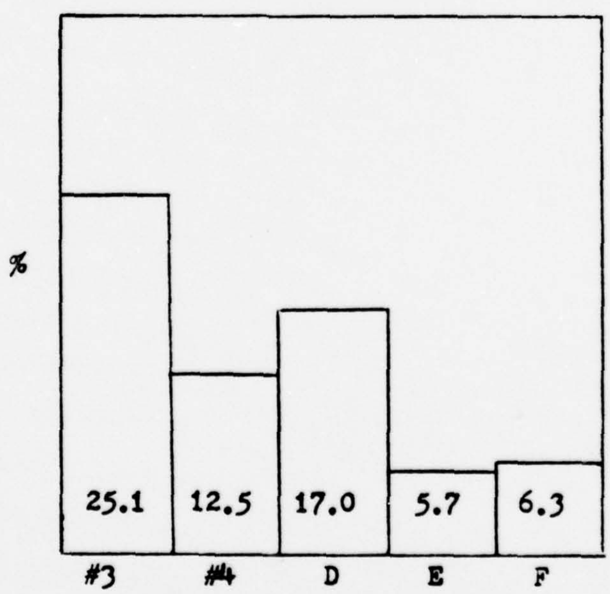
The volume required by the other ship operations functional category has a significant impact on the amount of internal volume required on a vessel. Figure 38 is a graphical representation of the other ship operations weight and volume fractions. Two observations can be made from this figure:

- The volume impact of other ship operations is far greater than the weight impact.
- Although the Naval oiler volume fractions are relatively large one of the commercial tankers has a relatively large volume fraction.

The other ship operations functional volume is comprised of seven volume subgroups:



OTHER SHIP OPERATIONS WEIGHT FRACTION



OTHER SHIP OPERATIONS VOLUME FRACTION

FIGURE 38 **Other Ship Operations Weight And Volume Fractions - Tankers**

•Control

•Maintenance

•Stowage

•Tankage

•Passageways and access

•Unassigned and temporarily unclassified

•Aviation

The amount of volume associated with the unassigned and temporarily unclassified volumes and with the aviation volumes on these vessels are negligible. Figure 39 is a graphical representation of the respective volume fractions for each of the remaining subgroups. The relatively large volume fractions of the Navy #3 vessel and tanker D are the result of the large amount of tankage volumes. This reflects the impact of the clean ballast system installed on these vessels. Cargo oil tanks are no longer used for ballast purposes.

Neglecting the amount of volume devoted to the clean ballast system, the volume fractions of the Naval vessels are about twice those of the commercial vessels. The control volume fractions are greater on the Naval vessels because of the amount of space dedicated to navigation and damage control.

The maintenance volumes are comprised of mechanical, electrical and general workshops. The Naval vessels alot more space to each of these functions. These facilities are needed to support the military payload and to maintain the various underway replenishment related equipments.

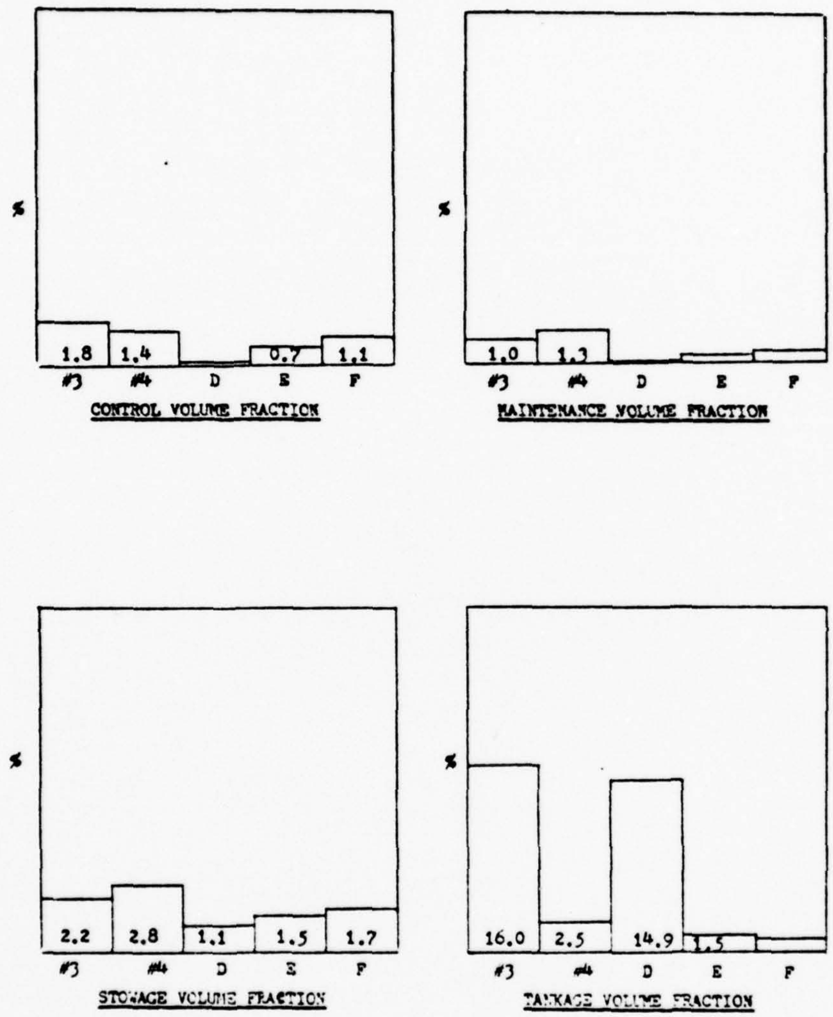


FIGURE 39 **Other Ship Operations Subgroup Volume Fractions - Tankers**

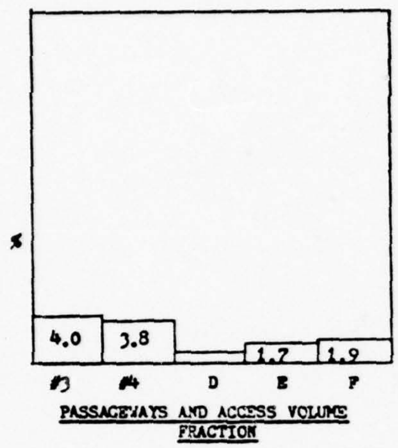


FIGURE 39 continued

Stowage volume is made up of the space dedicated to stores and supplies, boats and liferafts and motor vehicles. The Navy volume fractions are larger primarily because of the much larger crew size. Motor vehicle volume is negligible for all the vessels except Navy #4 which carries forklift trucks for cargo handling.

Passageway and access volumes are greater on the Naval vessels primarily because of the larger amount of subdivision within the hull and superstructures.

In order to explain the difference in the other ship operations weight fractions between the Naval and commercial vessels it is necessary to subdivide the other ship operations weight into the following four groups:

- Control
- Maintenance
- Ship systems
- Aviation

The weight associated with each of these groups is presented as a specific weight; the weight in pounds of a particular subgroup divided by the full load displacement. Table 31 displays these specific weights.

The magnitude of the ship system specific weight is the largest of the four groups and the value is greater for the Naval vessels. Ship systems is divided into the following categories:

- Hull fittings
- Boats, stowage and handling

TABLE 31

OTHER SHIP OPERATIONS SPECIFIC WEIGHTS -- TANKERS

Parameter	Units	Navy #3	Navy #4	D	E	F
Control Specific Weight	lbs/ton	4.5	3.8	0.4	0.9	0.9
Maintenance Specific Weight	lbs/ton	11.1	14.8	0.4	1.1	1.0
Ship Systems Specific Weight	lbs/ton	39.4	44.1	19.6	19.8	25.6
Aviation Specific Weight	lbs/ton	4.6	2.7	0	0	0

- Rigging and canvas
- Ladders and gratings
- Non-structural bulkheads
- Painting
- Deck covering
- Hull insulation

The significant differences are in boats, non-structural bulkheads, deck covering and hull insulation and these pertain primarily to vessel Navy #4. The deck coverings and hull insulation are greater due to the nature of the dry cargo carried by Navy #4. Non-structural bulkhead weights are larger because of the amount of subdivision on this vessel. The weights associated with boats are greater because of the larger crew size of the Naval vessels.

There is a substantial difference in the maintenance specific weights. This weight is comprised of four subgroups:

- Storerooms, stowages and lockers
- Equipment for utility spaces
- Equipment for workshops
- Outfit and furnishings spare parts

The Naval vessels have a significantly larger amount of weight in each category. This reflects primarily the more extensive maintenance facilities required on the Naval vessels because of the military payload and the underway replenishment capability.

The control specific weights are about three to five times larger for the Navy oilers. Control weight is comprised of three groups:

- Navigation equipment
- Interior communications systems
- Furnishings for electronics and radar spaces

The difference in specific weights is the result of the larger interior communication systems and the furnishings for electronics spaces. These are related to the military nature of the Naval vessels.

The aviation specific weights are zero for the commercial tankers. On the Naval vessels this weight is the result of the aviation fuel the vessels carry to refuel helicopters. Neither of the Navy oilers carry helicopters but they do have a helicopter landing platform and the ability to refuel helicopters.

From a dollar cost viewpoint, the other ship operations functional group would be more costly for the Naval vessels. This functional category is made up of a number of subsystems, many of which are more extensive on the Naval vessels and some of which are unique to the Navy oilers. The result is a greater acquisition cost both from an equipment point of view and from the labor needed to install it.

In summary, the following observations can be made concerning the other ship operations category.

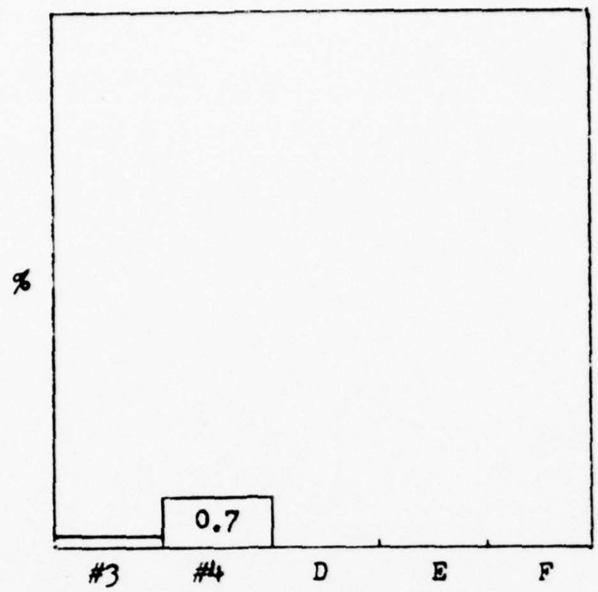
- The volume impact of other ship operations on all the vessels is significant.
- The segregated ballast system has a large volume impact on one of the Naval and one of the commercial tankers.

- Neglecting the volume associated with the segregated ballast systems, the other ship operations volume fractions of the Naval vessels are twice those of the commercial tankers. This is the result of the amount of space devoted to maintenance, stowage, control and passageways. These larger volumes reflect the greater emphasis placed on repair, and damage control facilities and the larger crew size of the Naval vessels.
- The weight impact of other ship operations is twice as great on the Naval vessels primarily because of the military nature of these vessels and also because of the support required for the underway replenishment capability.

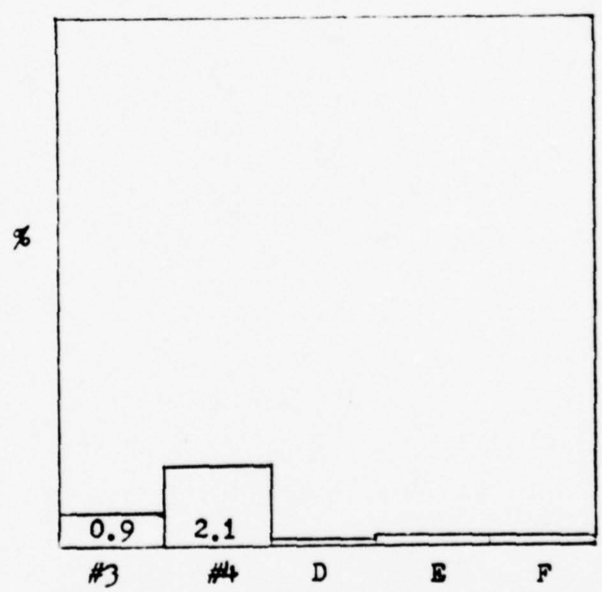
4.3.6 Military Payload

The military payload functional category has a very small impact on the Navy oilers and a negligible impact on the commercial tankers. Figure 40 displays the military payload weight and volume fractions. As can be seen the weight fractions are negligible for all the vessels except oiler #4. Military payload weight is comprised of the following groups:

- Guns, mounts and launching devices
- Ammunition and ammunition handling systems
- Ordnance stores
- Armament control system
- Countermeasure system (non-electronic)
- Electronic systems including electronic countermeasures



MILITARY PAYLOAD WEIGHT FRACTION



MILITARY PAYLOAD VOLUME FRACTION

FIGURE 40 Military Payload Weight And Volume Fractions - Tankers

For the Naval vessels, about 60% of the military payload can be attributed to guns and ammunition systems. The remainder is associated with armament control and electronics systems. The Navy oilers have weapons systems installed for defensive purposes only. Oiler #3 has weight reserved for two close-in weapons systems and oiler #4 has two twin 3"/50 caliber gun mounts.

For the commercial tankers, the only military payload weight is the weight of the radio communications, storage batteries and electrical navigating equipment. The weights associated with these systems have a negligible impact on the full load displacement.

Military payload has a greater impact in volume than in weight for the Naval vessels. The military payload volumes of the commercial tankers are negligible. Military payload volume is comprised of three groups:

- Communications, detection and evaluation
- Weapons spaces
- Special mission spaces

The larger military payload volumes on the Naval vessels are the result of weapons control and ammunition handling and stowage facilities. The only military payload volume for the commercial vessels is that of the communication spaces.

From a cost standpoint, military payload will obviously have a greater effect on the cost of the Naval vessels than on the cost of the commercial tankers because of the cost of the military systems and the associated labor cost to install it.

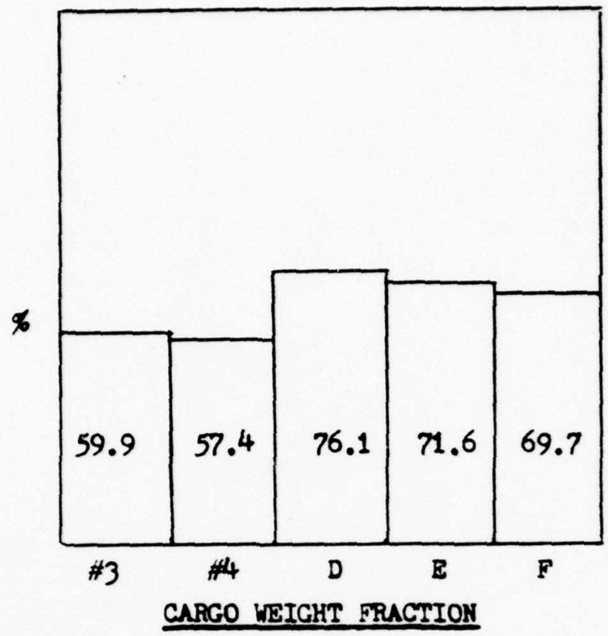
In summary, the following statements can be made concerning the military payload functional category:

- The impact of military payload is very small on the Navy oilers and negligible on the commercial tankers.
- The tankers have a military payload only in the sense that they have a communications and radar navigation capability. These items are standard on U.S. ocean-going vessels.
- The military payload does not account for a significant portion of the total difference between the Naval and commercial vessels.

4.3.7 Cargo Payload

There is a significant difference in cargo carrying ability between the Naval and commercial tankers. Figure 41 is a graphical representation of the cargo weight and volume fractions. For the same full load displacement, the commercial tankers carry about 20% more cargo by weight than the Navy oilers. The reason for the relatively small cargo weight fractions of the Naval vessels is because the basic vehicle weights are so high due primarily to the underway replenishment capability.

The cargo volume fractions of the commercial tankers are 60% greater than those of the Naval vessels. The reason the cargo volume fractions of the Naval vessels are relatively small is that many of the other functional categories have large volume impacts while the weight impacts are less.



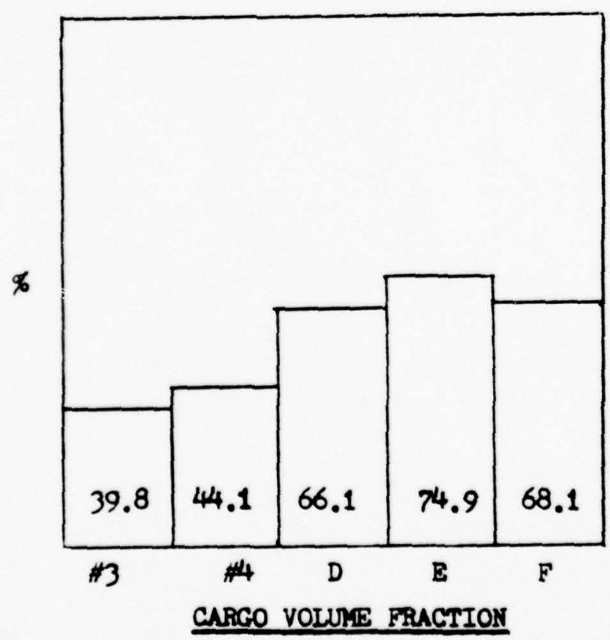


FIGURE 41 Cargo Weight And Volume Fractions - Tankers

The Navy oilers carry dry cargo in addition to petroleum products while the commercial tankers carry only petroleum products. Navy #3 carries only a very small amount of dry cargo, about .3% by weight. Navy #4 devotes about 4% of its cargo weight to various types of dry cargo. This dry cargo includes ammunition, mail, lube oil, and refrigerated stores.

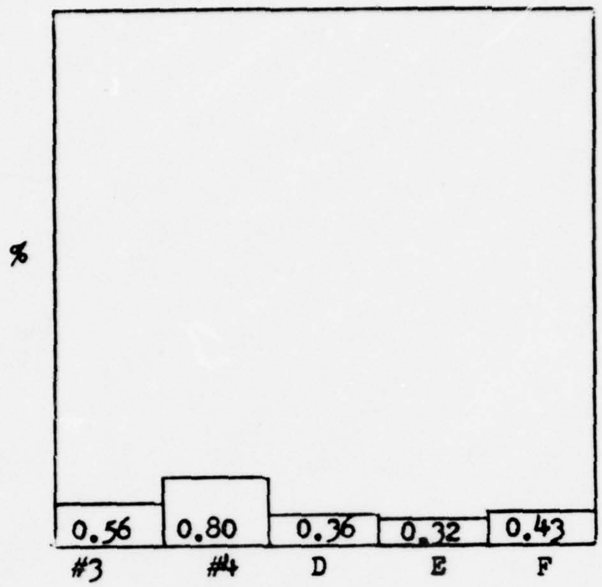
In summary, the following observations can be made relative to the cargo payload carrying abilities of the Navy oilers and commercial tankers:

- The Navy oilers carry 20% less cargo by weight than the commercial tankers.
- The Navy oilers carry dry cargo in addition to liquid cargo.

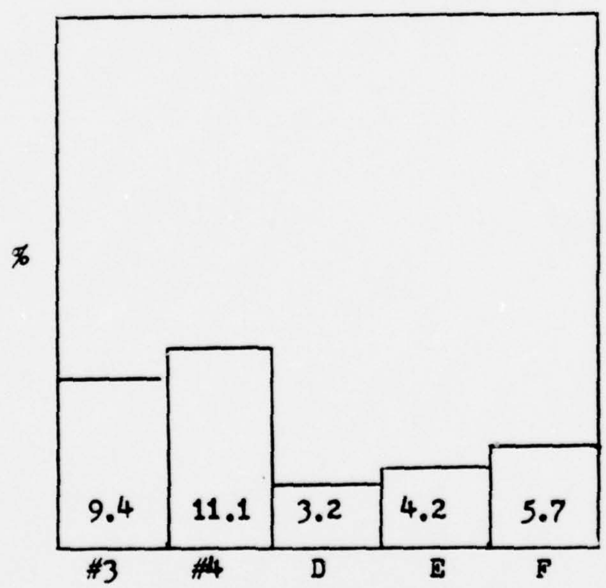
4.3.8 Personnel

The personnel area is one in which there are significant differences between the Naval and commercial tankers. The differences include almost an order of magnitude larger crew size and significantly lower habitability standards for the Naval vessels. Figure 42 is a graphical representation of the personnel weight and volume fractions.

As can be seen, the volume impact is significantly greater than the weight impact and has a much larger effect on the Naval vessels. In order to gain insight to the differences in the habitability standards between the Naval and commercial tankers it is necessary to examine the personnel specific volumes. This parameter reveals the amount of volume



PERSONNEL WEIGHT FRACTION



PERSONNEL VOLUME FRACTION

FIGURE 42 Personnel Weight And Volume Fractions - Tankers

that is devoted to each member of the crew. The personnel specific volumes of the commercial tankers are about 3.5 times larger than those of the Navy oilers.

	Navy #3	Navy #4	D	E	F
Personnel Specific Volume (ft^3/man)	1003	728	2565	3621	3401

The majority of this difference is the result of the amount of living space devoted to each man. In order to see this, the personnel specific volumes must be broken down into the following three categories:

- Living specific volumes
- Personnel support specific volumes
- Personnel stowage specific volumes

Parameter	Units	Navy #3	Navy #4	D	E	F
Living Specific Volume	ft^3/man	501	372	1924	2213	2215
Personnel Support Specific Volume	ft^3/man	427	222	468	719	604
Personnel Stowage Specific Volume	ft^3/man	74	134	173	688	582

The living volume category is comprised of berthing, sanitary and messing spaces. The habitability standards for the living spaces on these commercial tankers call for one-man staterooms with a toilet and shower

being shared by two men. The amount of space alloted to each man for these functions is far less on the Navy oilers.

The personnel support specific volumes are slightly less for the Naval vessels. Personnel support is comprised of the following types of spaces:

- Administration
- Food preparation and handling
- Medical and dental
- Personnel services
- Recreation and welfare spaces

Since the personnel support specific volumes do not vary significantly from vessel to vessel and since the crew sizes of the Navy tankers are about an order of magnitude larger, it becomes apparent that personnel support functions are a primary cause of the difference in the volume fractions between the Navy and commercial tankers.

The differences in the personnel stowage specific volumes are of secondary importance. These figures reflect an economy of size effect with respect to crew size. In terms of cubic feet devoted to this category there are only minor differences between the Navy and commercial tankers.

A comparison of the personnel specific volumes between Navy #3 and Navy #4 reflect the Navy's current emphasis on increased habitability standards. Navy #3 is a recent design and Navy #4 is about 8 years old.

The personnel weight fractions of the Naval vessels are about twice as great as those of the commercial tankers but the total impact on full load displacement is very small. The personnel weight fraction can be explained as the product of two quantities:

- •Personnel specific weight
- •Personnel capacity/ship size ratio

Table 32 shows the personnel weight fractions expressed as the product of these two parameters. Two observations can be made from this table. First, the personnel specific weights of the commercial tankers are about seven times greater than those of the Navy oilers. Second, the personnel capacity/ship size ratios of the Naval vessels are an order of magnitude greater than those of the commercial tankers. Each of these observations will be addressed separately.

The personnel specific weights of the Naval vessels are less for two reasons. First, the habitability standards are much lower on the Naval vessels and second, there is an economy of size effect. In order to reveal these effects, it is necessary to divide the personnel weights into the following three categories:

- •Living weight
- •Personnel support weight
- •Personnel stowage weight

TABLE 32

PERSONNEL WEIGHT FRACTION EXPRESSED AS THE PRODUCT OF THE PERSONNEL SPECIFIC WEIGHT AND THE PERSONNEL CAPACITY/SHIP SIZE RATIO

Vessel	Personnel Weight Fraction x 100 (%)	=	Personnel Specific Weight (tons/man)	x	Personnel Capacity/Ship Size Ratio (men/100 tons)	x	Conversion Factor (1/100)
Navy #3	0.56		0.80		.68		1/100
Navy #4	0.80		0.70		1.15		1/100
D	0.36		5.47		.06		1/100
E	0.32		5.31		.06		1/100
F	0.43		4.53		.09		1/100

Parameter	Units	Navy #3	Navy #4	D	E	F
Living Specific Weight	tons/man	0.31	0.21	0.84	0.83	0.64
Personnel Support Specific Weight	tons/man	0.08	0.08	0.11	0.29	0.21
Personnel Stowage Specific Weight	tons/man	0.41	0.40	4.5	4.2	3.7

Living specific weight is comprised of furnishings for living spaces and the load item, crew and effects. The amount of furnishings alloted for each Navy crew member is considerably less than that alloted to a merchant crew member. This reflects the lower habitability standards of the Navy.

The personnel support specific weight is made up primarily of galley, pantry, scullery and commissary outfittings. The magnitude of the support specific weight shown above are slightly less for the Naval vessels primarily because of an economy of size effect.

The personnel stowage specific weight is made up of potable water, provisions and stores. The relative magnitudes of the personnel stowage specific weights reflect the greater amount of fresh water alloted to each crew member on the commercial tankers and the larger amount of provisions and stores carried for each crew member.

As can be seen in table 32, the personnel capacity/ship size ratios of the Naval vessels are almost an order of magnitude larger than those of the commercial vessels. In order to investigate crew size differences it is convenient to break crew size down into the following five categories:

- Deck
- Engineering
- Steward
- Officers
- Other

	Navy #3	Navy #4	D	E	F
Deck	80	196	9	9	9
Engineering	66	131	4	3	6
Supply	26	86	3	3	5
Officers	11	19	9	10	10
Other	--	--	6	2	2
Total	183	432	31	27	32

The deck complement for the Navy oilers is greater because of the military payload, such as weapons, electronics, communications and evaluations and because of the underway replenishment capability.

There is a significant difference in the engineering department crew size between the Navy and commercial tankers. The engineering department on the Naval vessels include not only the engine room and fireroom personnel, but also machinery repairmen, damage controlmen, internal communication specialists, electricians and enginemen.

Supply crew size differences can be explained primarily by the fact that the larger crew size of the Naval vessels necessitate more support and administrative personnel and by the fact that the underway

replenishment capability requires a large number of supply department personnel. Navy #4 requires so many supply personnel in part because this vessel carries dry cargo as well as petroleum products.

In summary, the personnel weight fractions of the Navy oilers are larger than those of the commercial tankers because of the larger crew size. The Navy's lower habitability standards reduce the impact of personnel weight on full load displacement. The use of commercial habitability standards on the Navy oilers without a substantial reduction in crew size would have a drastic impact on the total internal volume required.

From a cost standpoint, the personnel functional group has a much greater impact on the building cost of the Naval vessels. This is due to the larger crew size. The cost of the furnishingings and personnel support equipments on the Navy oilers would be significantly greater. Indirectly, the personnel functional category impacts the hull structural costs because of the effect of personnel on the amount of internal volume required.

In summary, the following observations can be made concerning the personnel functional category:

- The weight and volume impact of personnel is much greater on the Naval vessels. Of the two, the volume impact predominates.
- Personnel volume requirements have a significant impact on the amount of enclosed volume that is required for the Navy oilers.

- Personnel volume requirements are greater on the Naval vessels because of the difference in crew size between the Navy and commercial tankers.
- The larger weight impact of personnel on the Naval vessels is also the result of the greater crew size.
- The habitability standards of the Naval vessels are considerably lower than the commercial standards in terms of both the weight and volume devoted to each man.
- The lower habitability standards of the Naval vessels reduce the impact of personnel weight and volume on ship size relative to what it would be if commercial habitability standards were used on the Naval vessels.

4.3.9 Liquids

With the exception of the cargo and the structural weight fractions, the liquids weight fraction has a greater impact on full load displacement than any of the other functional categories. The liquids volume fractions have less of an impact because the density of liquids is much greater than that of the other functional categories.

Figure 43 displays the liquids weight and volume fractions. As can be seen, the weight impact of liquids varies from vessel to vessel. Liquids is comprised of the weights associated with the following items:

- Endurance fuel oil
- Reserve feed and demineralized water

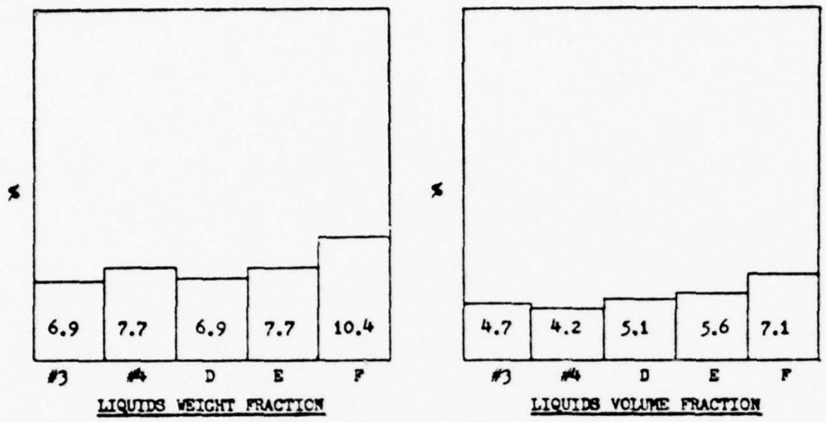


FIGURE 43 Liquids Weight And Volume Fractions - Tankers

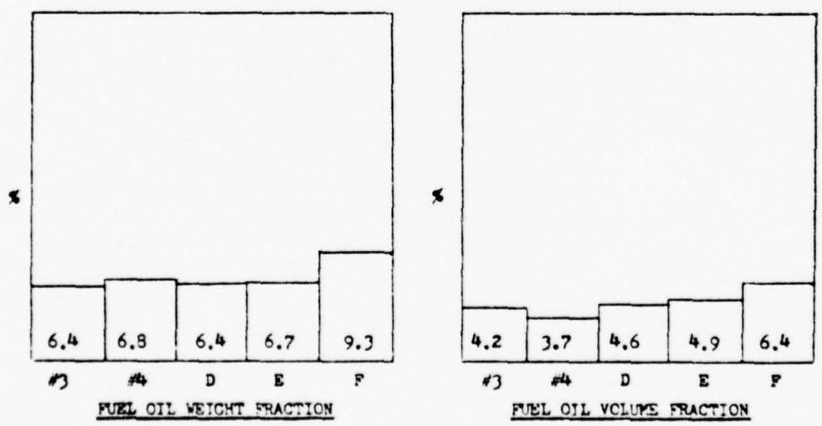


FIGURE 44 Fuel Oil Weight And Volume Fractions - Tankers

- Lube oil
- Miscellaneous liquids
- Piping tunnels

As can be seen from figure 44, the endurance fuel oil accounts for the vast majority of the liquids weight fractions for each of the vessels. There are no significant differences between the Naval and commercial vessels in the weight fractions associated with the other liquids subgroups.

The endurance ranges of the commercial tankers are about twice those of the Navy oilers but the commercial tankers do not carry twice as much fuel. The reason for this is the greater endurance speeds of the Naval vessels and the larger electrical cruising load.

In summary, the following statements can be made concerning the impact of liquids on the Navy oilers and the commercial tankers.

- The weight impact of liquids on full load displacement relative to the other functional categories is large for all the vessels.
- The majority of the liquids category is made up of endurance fuel oil.
- The Navy oilers have only half the endurance range of the commercial tankers but carry more than half as much endurance fuel oil because of their higher cruising speed and larger electrical cruising load.

Section 4.4 Summary and Conclusions

With the comparison of Navy oilers and commercial tankers, several observations and conclusions can be stated:

- From a commercial point of view, the Navy oilers are poor performers relative to the commercial tankers. They carry 20% less cargo by weight than the commercial tankers and are more expensive to build and operate.
- There are three factors which contribute to the differences which exist between the Navy oilers and the commercial tankers:
  (1) the underway replenishment capability
  (2) the military capabilities of the Navy oilers
  (3) the design criteria and practices used by Naval designers
- A large portion of the differences which exist between the Navy and commercial tankers can be traced directly or indirectly to the underway replenishment capability.
- The greatest impact of the underway replenishment capability is in the total internal volume that is required.
- The volume impact is so large primarily because of the volume associated with the auxiliary, other ship operations and personnel functional categories. Indirectly volume has a large impact on structural weight.
- The weight impact of the underway replenishment capability is also significant. The weight impact manifests itself in the electrical auxiliary, other ship operations and personnel categories.

- The military capabilities of the Navy oilers are responsible for a significant protion of the differences which exist between the Navy oilers and the commercial tankers. The military capability which has the largest effect on the design of the Navy oilers is the greater speed requirement.
- The greater speed requirement results in a larger propulsion plant and a finer hull form. The finer hull form impacts the structural weight and the hull construction cost.
- The military nature of the Navy oilers is manifested by the greater emphasis on damage control and maintenance facilities. The impact of these characteristics are felt primarily in the auxiliary, other ship operations and structural functional groups. The impact of these characteristics are of secondary importance in explaining the difference which exists between Navy oilers and commercial tankers.
- Differences between the Naval and commercial vessels caused by the larger military payload of the Naval vessels are of secondary importance in explaining the weight and volume differences between the Navy oilers and the commercial tankers. The greatest impact of the military payload is in the personnel functional group.
- Differences in design criteria or practices used by the Navy and commercial designers exist primarily in the structural and main propulsion functional groups. Navy

structural design procedures result in reduced structural weight but at a higher cost. Differences in main propulsion practice exist primarily with the propulsion support equipment and in the volume devoted to main propulsion. The Navy's propulsion support practices are more costly than the commercial practice.

CHAPTER 5

SUMMARY AND RECOMMENDATIONS

The following observations can be made concerning the comparison of Naval auxiliary and commercial vessels:

(1) Naval replenishment vessels carry significantly less cargo than commercial vessels because of the underway replenishment and the military capabilities of the Naval vessels.

(2) The underway replenishment capability has the predominate impact on Naval auxiliary vessel design.

(3) The replenishment capability has a large impact on the structural weight, the electrical capacity, the auxiliary systems and the crew size of the Naval vessels.

(4) The military capabilities of the Naval auxiliaries are highlighted by the greater emphasis on speed, damage control, redundancy, maintenance facilities and military payload.

(5) The Navy's requirement for greater speed has the largest impact of the military capabilities on the design of the Naval vessels.

(6) The direct impact of military payload on full load displacement and total internal volume is small. Indirectly, the military payload accounts in part for the greater crew sizes of the Naval vessels.

(7) The differences in the design criteria and practices of the Naval and commercial designers are of secondary importance in explaining the differences which exist between the Naval auxiliary and the commercial vessels used in this study.

(8) From a cost standpoint, a significant portion of the differences in acquisition cost can be explained by the underway replenishment capabilities and the military capabilities of the Naval vessels.

(9) There are certain Navy structural and main propulsion support equipment practices which result in higher cost.

The following areas are recommended for further study:

(1) A detailed comparison of Naval auxiliary and commercial structural design practices.

(2) A detailed comparison of Naval auxiliary and commercial main propulsion design practices, particularly in the area of propulsion support subsystems.

(3) A comprehensive evaluation of the cost impact of the Navy's testing, inspection, and progress reporting requirements for Naval auxiliary type vessels.

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APPENDIX A

WEIGHT AND VOLUME BREAKDOWN OF FUNCTIONAL CATEGORIES

The following is the classification system used in defining the functional categories used in this analysis. Volume group numbers refer to the Proposed U.S. Navy Ship Space Classification System.[2] Weight group numbers refer to the U.S. Navy's Bureau of Ships Consolidated Index (BSCI). The Maritime Administration weight classification is also presented. The weight conversion from the Marad system to the BSCI system is based on a modified version of reference 1.

STRUCTURE

	BSCI	MARAD	DESCRIPTION
Weight	100	1-0 1-1 1-2 1-3 1-4 1-5	Shell Plating or Planking
	101	2-0 2-1 2-2 2-3 2-4 2-5 2-6 2-7 5-0 thru 5-9 (25%) 6-5 6-6 (50%)	Longitudinal and Transverse Framing
	102	6-0	Inner Bottom Plating
	103	6-1 6-4 6-6 (50%)	Platforms and Flats Below Lowermost Continuous Deck

104	3-3 5-3 (75%)	Fourth Deck
105	3-2 4-8 (10%) 5-2 (75%)	Third Deck
106	3-1 4-8 (60%) 5-1 (75%)	Second Deck
107	3-0 4-8 (60%) 5-0 (75%)	Main Deck
108	3-4 5-4 (75%) 4-8 (20%)	Forecastle Deck
111	8-0 thru 8-7 (85%) 8-8 8-9 14-0	Superstructure
112	7-0 7-1 7-3	Foundations of Main Propelling Machinery
113	7-2 7-4 7-9	Foundations for Auxiliaries and Other Equipment
114	4-0 4-1 4-2 4-3	Structural Bulkheads
115	4-5 4-6 4-7 8-0 thru 8-7 (5%)	Trunks and Enclosures
119	0-0 0-1 0-2 0-3 0-4 11-0 (40%)	Structural Castings, Forgings and Equivalent Weldments
120	20-5 (20%)	Sea Chests

122	10-2 12-0 13-1	Doors and Closures, Special Purpose
123	12-1 12-2 12-4 12-5	Doors, Hatches, Manholes and Scuttles-Non Ballistic
125	10-0 11-1 (75%)	Masts and Kingposts
150	9-0 9-1 9-2	Welding, Riveting and Fastening

MAIN PROPULSION

	NAVSEC SPACE	Description
Volume	3.2	Main Propulsion Machinery

	BSCI	MARAD	Description
Weight	200	26-0 26-1 26-2	Boilers and Energy Converters
	201	20-0 20-1 20-2 25-1 25-2 28-2	Propulsion Units
	202	20-3 20-4	Main Condensers and Air Ejectors
	203	23-0 23-1 23-2 23-3	Shafting, Bearings and Propellers
	204	26-3	Combustion Air Supply

205	26-5	Uptakes and Smokepipes
206	26-4	Propulsion Control Equipment
207	27-0	Main Stream System
208	21-0 21-1 22-0	Feed Water and Condensate System
209	20-5 (80%)	Circulating and Cooling
210	26-6	Fuel Oil Service System
211	24-0 24-1 (80%)	Lubricating Oil System
250	23-4 28-5 (90%)	Propulsion Repair Parts
251	29-1 29-2	Propulsion Operating Fluids

ELECTRICAL

	NAVSEC SPACE	Description
Volume	3.33	Electrical Systems

	BSCI	MARAD	Description
Weight	300	19-3A 19-3B 19-3C 19-3G (50%) 24-1	Electric Power Generation
	301	19-3D (70%)	Distribution (Switchboard)
	302	19-3E (60%)	Distribution (Cable)
	303	19-3D (20%) 19-3E (40%) 19-3F 19-3G (25%)	Lighting System

	350	--	Repair Parts

AUXILIARY

	NAVSEC SPACE	Description
Volume	1.52	Cargo Handling
	1.53	Auxiliary Services
	1.54	Cargo Offices
	1.55	Cargo Shops
	3.31	Engineering Auxiliaries
	3.32	Deck Auxiliaries

	BSCI	MARAD	Description
Weight	500	17-1 19-5	Heating System
	501	17-2 17-3 28-3	Ventilation System
	502	17-4 (20%)	Refrigerating System
	503	17-4 (80%)	Air Conditioning System
	504	18-1 (80%)	Gas, HEAF, Cargo Piping, Oxygen- Nitrogen, Aviation Lubricating Oil Systems
	505	17-5 (85%)	Plumbing Fixtures and Drains
	506	18-3 18-4 (20%)	Firemain, Flushing, Sprinkler and Salt Water Service Systems
	507	17-0 (90%)	Fire Extinguishing
	508	18-0 18-7 (50%) 18-8 (50%)	Drainage, Trimming, Heeling and Ballast Systems

509	18-4 (80%)	Fresh Water Systems
510	17-6	Deck Scuppers
511	18-5 (80%) 18-6 18-7 (50%) 18-8 (50%)	Fuel Oil and Diesel Oil Filling, Venting, Stowage and Transfer Systems
512	18-1 (20%) 18-5 (20%)	Tank Heating System
513	25-0	Compressed Air System
514	18-2 22-1 27-1 27-2 27-3	Auxiliary Steam, Exhaust System and Steam Drain
516	----	Miscellaneous Piping Systems
517	19-6 22-2	Distilling Plant
518	19-1 (35%) 19-7	Steering Gear and Rudder Stabilizers
519	19-1 (65%)	Rudder
520	15-0	Winches, Capstans, Cranes and Anchor Handling System
521	10-1 11-1 (25%) 15-2 (60%) 19-0 (60%) 19-4	Elevators, Cargo and Load Handling Equipment
550	28-5 (10%)	Auxiliary Systems Repair Parts
551	29-0	Auxiliary Systems Operating Fluids

OTHER SHIP OPERATIONS

	NAVSEC SPACE	Description
Volume	1.3	Aviation

3.1		Control
3.4		Maintenance
3.5		Stowage
3.6		Tankage
3.7		Passageways and Access
3.8		Unassigned
3.9		Temporarily Unclassified

	BSCI	MARAD	Description
Weight	400	15-4 19-3H (40%) 27-4	Navigational Systems and Equipment
	401	17-0 (10%) 19-2B 19-2C 19-3D (10%)	Interior Communications System
	600	11-0 (60%) 11-2 11-4 11-5 12-3 12-6 13-0 (75%) 13-3 (50%)	Hull Fittings
	601	13-0 (25%) 15-1 15-2 (5%)	Boats, Boat Stowage and Handling
	602	15-2 (35%) 15-3	Rigging and Canvas
	603	10-3 11-3 14-5 28-0	Ladders and Gratings
	604	4-4 8-0 thru 8-7 (10%)	Nonstructural Bulkheads and Doors

	13-3 14-1 14-4		
605	15-8		Painting
606	13-7 13-8 13-9 14-3 15-9		Deck Covering
607	14-8 14-9		Hull Insulation
608	10-4 13-2		Storerooms, Stowages and Lockers
609	16-1	(30%)	Equipment for Utility Spaces
610	28-1		Equipment for Workshops
650	----		Outfit and Furnishings Spare Parts
Helo			
Helo Stores			
Aviation Lube Oil			
Aviation Fuel			

MILITARY

	NAVSEC SPACE	Description
Volume	1.1	Communications, Detection and Evaluation
	1.2	Weapons
	1.37	Aircraft Ordnance
	1.8	Special Missions

	BSCI	MARAD	Description
Weight	402	-----	Armament Control Systems
	403	16-4 16-5	Countermeasured and Ship Protective Systems (Except Electronics)
	404	19-2A 19-3G (25%) 19-3H (60%)	Electronic Systems Including Electronic Countermeasures
	450	-----	Communication and Control Repair Parts
	700	16-8	Guns, Mounts and Launching Devices
	701	16-6 (20%)	Ammunition Handling Systems
	702	16-6 (80%)	Ammunition Stowage
	750	-----	Armament Repair Parts
	751	-----	Armament Operating Fluids
	Ordnance Stores		
	Ship Ammunition		

CARGO

	NAVSEC SPACE	Description
Volume	1.511	Dry Cargo Stowage
	1.512	Liquid Cargo Stowage
	1.513	Refrigerated Cargo Stowage

	BSCI	MARAD	Description
Weight	Dry Cargo		
	Liquid Cargo		
	Refrigerated Cargo		

PERSONNEL

	NAVSEC SPACE		Description
Volume	2.1		Living
	2.2		Supporting Functions
	2.3		Stowage
	BSCI	**MARAD**	**Description**
Weight	612	14-2 16-2 17-5 (15%)	Furnishings for Living Space
	611	16-0	Equipment for Galley, Pantry, Scullery and Commissary Outfit
	614	16-1 (10%)	Furnishings for Medical and Dental Spaces
	Crew and Effects		
	Potable Water		
	Provisions and Stores		
	General Stores		

LIQUIDS

	NAVSEC SPACE		Description
Volume	3.511		Endurance Fuel Oil
	3.512		Reserve Feed and Demineralized Water
	3.513		Lubricating Oil
	3.514		Miscellaneous Liquids
	3.515		Piping Tunnels
	BSCI	**MARAD**	**Description**
	Fuel Oil		

Feed Water

Lube Oil

Miscellaneous Liquids

APPENDIX B

SHIP DATA

Weights and volumes for each of the vessels used in the analysis are presented for reference in this appendix.

TABLE B-1

CARGO VESSEL WEIGHT DATA (TONS)

	Navy #1	Navy #2	A	B	C
Structure	5205.8	5346.6	3982.6	5186.6	4918.5
Main Propulsion	725.7	784.6	652.2	845.2	779.1
Electrical	241.3	179.6	124.8	119.5	123.2
Auxiliary	2605.0	1666.3	677.3	1027.7	750.8
Other Ship Operations	859.0	1039.9	514.5	591.3	542.4
Military Payload	316.5	208.6	3.4	5.5	4.1
Cargo Payload	5495.1	4110.1	8919.0	10224.0	10937.1
Personnel	304.1	373.3	191.4	154.1	109.7
Liquids	2836.4	2390.7	2143.7	2897.7	2794.1
Δ	18,589	16,100	17,210	21,053	20,959

TABLE B-2

CARGO VESSEL VOLUME DATA (FT^3)

	Navy #1	Navy #2	A	B	C
Main Propulsion	227,400	186,400	124,600	150,700	143,100
Electrical	11,100	6,600	1,600	1,900	2,400
Auxiliary	522,300	216,800	22,100	43,900	45,700
Other Ship Operations	312,900	250,900	88,200	130,500	107,500
Military Payload	55,700	49,400	2,200	1,900	2,300
Cargo Payload	464,300	700,300	680,700	749,100	817,600
Personnel	268,200	291,700	88,600	90,700	86,700
Liquids	120,000	112,200	115,800	105,400	92,800
Total Volume	1,981,900	1,814,300	1,123,800	1,274,100	1,298,100

TABLE B-3

NAVY OILER AND COMMERCIAL TANKER WEIGHT DATA (TONS)

	Navy #3	Navy #4	D	E	F
Structure	5583.9	8389.7	6150.2	7195.5	4819.1
Main Propulsion	758.7	1085.8	578.5	441.7	606.6
Electrical	213.6	326.8	65.1	65.7	95.8
Auxiliary	1241.8	1698.2	622.2	831.2	721.6
Other Ship Operations	695.9	1090.2	431.2	431.8	416.7
Military Payload	37.6	267.0	7.7	4.8	6.1
Cargo Payload	15711.2	21585.5	36000.0	31600.0	23700.0
Personnel	147.2	300.8	169.8	143.5	145.1
Liquids	1815.4	2886.4	3274.7	3395.2	3536.3
Δ	26,205	37,630	47,281	44,150	33,990

TABLE B-4

NAVY OILER AND COMMERCIAL TANKER VOLUME DATA (FT^3)

	Navy #3	Navy #4	D	E	F
Main Propulsion	235,600	344,600	237,500	176,000	190,100
Electrical	11,500	8,300	2,300	3,300	3,400
Auxiliary	143,300	397,600	30,600	42,500	46,800
Other Ship Operations	488,400	359,300	361,100	135,400	119,300
Military Payload	17,900	61,600	1,900	1,900	2,200
Cargo Payload	776,200	1,276,900	1,637,500	1,766,400	1,294,000
Personnel	183,600	319,900	79,500	98,800	108,400
Liquids	91,800	120,000	126,700	132,900	135,400
Total Volume	1,948,300	2,881,300	2,477,100	2,357,200	1,899,600

APPENDIX C

FUNCTIONAL SUBGROUP WEIGHTS AND VOLUMES

The BSCI weights and the NAVSEC volumes associated with the subgroups of each functional category discussed in Chapters 3 and 4 are presented for reference in this appendix.

I. WEIGHT

STRUCTURE	BSCI WEIGHT GROUP
Hull framing, plating and inner bottom plating	100
	101
	102
Decks, platforms and flats	103
	104
	105
	106
	107
	108
	109
	110
Superstructures	111
Foundations	112
	113
Structural bulkheads	114
Doors and hatches	123
Masts and kingposts	125
	128
Remainder	115
	119
	120
	121
	150

MAIN PROPULSION	
Energy generation	200
Propulsion unit	201
Propulsor	203

Propulsion support	202 204 205 206 207 208 209 210 211 250
Propulsion operating fluids	251
<u>ELECTRICAL</u>	
Electric power generation	300
Distribution (switchboard)	301
Distribution (cable)	302
Lighting system	303
Repair parts	350
<u>AUXILIARY</u>	
Climate control system	500 501 502 503
Sea water systems	506 508 510(50%) 505(50%)
Fresh water systems	509 514 517 505(50%) 510(50%)

Fuel and lubricants systems	504(80%)
	511
	512
Air, gas and miscellaneous fluid systems	504(20%)
	507
	513
	516
Ship control systems	515
	518
	519
Underway replenishment systems	521
	528
Mechanical handling systems	520
	522
	523
	524
	525
Auxiliary system repair parts	550
Auxiliary system operating fluids	551

<u>OTHER SHIP OPERATIONS</u>

Control	400
	401
	613
Maintenance	608
	609
	610
	650
Ship Systems	600
	601
	602
	603
	604
	605
	606
	607

Aviation	helo aeronautical stores aviation lube oil aviation fuel
<u>MILITARY PAYLOAD</u>	402 403 404 450 700 701 702 703 750 751 ordnance stores ship ammunition
<u>CARGO PAYLOAD</u>	dry cargo liquid cargo refrigerated cargo
<u>PERSONNEL</u>	
Living	612 crew and effects
Support	611 614
Storage	potable water provisions and stores
<u>LIQUIDS</u>	fuel oil reserve feed water lube oil miscellaneous liquids

II. VOLUME

	NAVSEC SPACE CLASSIFICATION
MAIN PROPULSION	3.2
ELECTRICAL	3.3
AUXILIARY	
Cargo handling	1.52
Auxiliary services	1.53
Offices	1.54
Shops	1.55
Engineering auxiliaries	3.31
Deck auxiliaries	3.32
OTHER SHIP OPERATIONS	
Aviation	1.3
Control	3.1
Maintenance	3.4
Stowage	3.5
Tankage	3.6
Passageways and access	3.7
Unassigned	3.8 3.9
MILITARY PAYLOAD	1.1 1.2 1.37 1.8

CARGO PAYLOAD

Dry cargo	1.511
Liquid cargo	1.512
Refrigerated cargo	1.513

PERSONNEL

Living	2.1
Support	2.21 2.22 2.23 2.24 2.25
Storage	2.3

LIQUIDS

Endurance fuel oil	3.511
Reverve feed water	3.512
Lube oil	3.513
Miscellaneous liquids	3.514